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NAVAL POSTGRADUATE SCHOOL MONTEREY CA A W MCMASTERS
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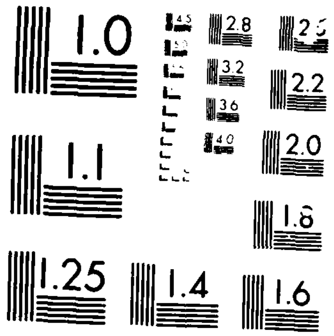
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NAVAL POSTGRADUATE SCHOOL

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WHOLESALE PROVISIONING MODELS:
MODEL EVALUATION

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MAY 1986

Prepared for:

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86 6 30 045

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The work reported herein was supported with funds provided by the Navy Fleet Material Support Office, Mechanicsburg, Pennsylvania.

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SECURITY CLASSIFICATION OF THIS PAGE

AD-A170 927

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S) NPS55-86-011	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION Naval Postgraduate School; 6b OFFICE SYMBOL (If applicable)	7a NAME OF MONITORING ORGANIZATION Fleet Material Support Office
6c ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000	7b ADDRESS (City, State, and ZIP Code) Mechanicsburg, PA 17055
8a NAME OF FUNDING / SPONSORING ORGANIZATION Fleet Material Support Office; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code) Mechanicsburg, PA 17055	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)

WHOLESALE PROVISIONING MODELS: MODEL EVALUATION

12 PERSONAL AUTHOR(S)

MCMASTERS, ALAN W.

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
TECHNICAL	FROM ______ TO ______	1986 May	113

16 SUPPLEMENTARY NOTATION

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Inventory Models, Provisioning, Mean Supply Response Time, Model Evaluation

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Two models were proposed in an earlier report to replace the current models for determining the initial range and depth of wholesale level inventories of secondary items managed by the Navy's Ships Parts Control Center (SPCC) and the Aviation Supply Office (ASO). The objectives of these models were to minimize the aggregate mean supply response time (MSRT) or to maximize the aggregate gross effectiveness (G-E) for the spare and repair parts of a new weapon system. The constraint in each model was the budget available to procure the parts. This report presents the evaluation of the proposed models using data from seven actual systems previously provisioned by SPCC and five actual systems previously provisioned by ASO. The Navy's criterion for accepting a new model was that it had to provide at least a 5% improvement over the existing models, the Variable Threshold (VT) model of SPCC and the D52 model of ASO, using aggregate mean supply response time and aggregate gross effectiveness as the performance measures. The evaluations showed that the MSRT model easily satisfied this criterion for ten of the systems and gave the same results as the existing models for the

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION
22a NAME OF RESPONSIBLE INDIVIDUAL Alan W. McMasters	22b TELEPHONE (Include Area Code) (408)646-2678; 22c OFFICE SYMBOL Code 55Mg

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

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ABSTRACT

Two models were proposed in an earlier report to replace the current models for determining the initial range and depth of wholesale level inventories of secondary items managed by the Navy's Ships Parts Control Center (SPCC) and the Aviation Supply Office (ASO). The objectives of these models were to minimize the aggregate mean supply response time (MSRT) or to maximize the aggregate gross effectiveness (G-E) for the spare and repair parts of a new weapon system. The constraint in each model was the budget available to procure the parts. This report presents the evaluation of the proposed models using data from seven actual systems previously provisioned by SPCC and five actual systems previously provisioned by ASO. The Navy's criterion for accepting a new model was that it had to provide at least a 5% improvement over the existing models, the Variable Threshold (VT) model of SPCC and the D52 model of ASO, using aggregate mean supply response time and aggregate gross effectiveness as the performance measures. The evaluations showed that the MSRT model easily satisfied this criterion for ten of the systems and gave the same results as the existing models for the other two. The G-E model did not perform as well but did perform better than the current models for the same ten systems and gave the same results as the existing models for the other two systems. As a consequence of these evaluations, the Navy accepted the MSRT model in December of 1984.

1. INTRODUCTION

1.1 BACKGROUND

In the spring of 1982, the Naval Supply Systems Command (NAVSUP) asked the Naval Postgraduate School (NPS) to develop improvements to the existing peacetime wholesale provisioning models for secondary items used by the Ships Parts Control Center (SPCC) and the Aviation Supply Office (ASO). This effort was motivated by NAVSUP's Resolicitation Project, the major objective of which was to acquire new computer hardware. However, it also provided an opportunity to take a hard look at existing models in use by NAVSUP's Inventory Control Points (ICPs), SPCC and ASO, and to make appropriate changes to them as the ICP software was being moved from the old to the new computers. Wholesale model improvements for both initial provisioning and replenishment of secondary items were top priority [1].

During 1982 and 1983, the question of appropriate wholesale provisioning models was investigated. As a consequence of this investigation, three alternatives to the existing Navy models were developed and the details were reported in Reference 2. The alternatives were optimization models designed to minimize or maximize a measure of effectiveness for a given provisioning budget. Their measures of effectiveness were:

1. Essentiality-weighted units or requisitions short;
2. Essentiality-weighted time-weighted units or requisitions short;
3. Operational availability.

The phrase "units or requisitions short" means that there is no stock available to fill demand at the time the requisitions are received. These requisitions are assumed to be backordered until a replenishment buy is received by the supply system.

Because of the assumptions required to justify it and the difficulty of obtaining data to run it, the "Operational Availability" model was considered by NAVSUP personnel to be an infeasible alternative for the foreseeable future.

The objective function of the model associated with the "units short" measure in Reference 2 was the ratio of expected demands filled to the total expected demands over a specified time interval. This is a "positive" measure of performance which is directly related to units short since expected demands filled is the difference between total expected demands and the expected number of units short over the specified time interval. The model then seeks to maximize this objective function.

This model was initially called the "Supply Material Availability" or "SMA" model in Reference 2 because of its close resemblance to the SMA formulas used by SPCC and ASO. However, the model name was changed at the request of NAVSUP personnel to Gross Effectiveness (G-E) since it actually is equivalent to that measure as it is defined by the ICPs. The important difference between SMA and G-E is that SMA measures only the performance of items carried in stock whereas G-E includes both stocked and non-stocked items [3]. G-E is the more appropriate for initial provisioning since it measures the impact of not stocking an item.

The objective function of the model associated with the time-weighted units short measure in Reference 2 was the mean supply response time (MSRT). The goal was to minimize MSRT. MSRT is of special significance because of its role in the definition of Operational Availability (A_O) [4]. Under the assumption that the number of demands over time is a Poisson random variable, the MSRT formula is the ratio of the expected time-weighted units short to the expected demand over the same specified interval of time. In contrast to the current use of the mean supply response time by the Navy, where times to move an item from one echelon to the next are the major considerations [3], the time interval in the MSRT model concentrates on the time between the material support date (MSD) and the arrival of the first replenishment buy into the wholesale system. This period is at least as long as the procurement lead time (PCLT). Time to move on-hand stocks to customers is negligible when compared to the usual PCLT values.

A simple numerical example was solved to provide an illustration of the improved performance that could be expected from the G-E, MSRT, and A_o models when compared to the current model used by SPCC. The example assumed a package of 25 consumable items. The budget and item parameters were generated arbitrarily and each model was evaluated on how well its allocation of the budget performed relative to the G-E, MSRT, and A_o measures of effectiveness. The optimization technique used for the G-E and MSRT models was marginal analysis. As expected, the G-E model allocation provided the highest value of G-E, the MSRT model allocation provided the lowest MSRT value and the A_o model provided the highest operational availability.

However, in spite of optimization arguments and the example results, NAVSUP personnel stated that for the new model to be approved by the chain of command, actual systems which had recently been provisioned should be "reprovisioned" using the proposed models as a means of evaluating their expected performance. At least a 5% improvement over the current NAVSUP models was required for a new model to be approved. Therefore, the details of these existing provisioning models would need to be understood and programmed. These were the Variable Threshold (VT) model of SPCC and the D52 model of ASO. Finally, since the budget generation process must continue to follow the COSDIF procedure of DODINST 4140.42 [5], at least one of the current ICP implementations of that procedure would also have to be programmed. The SPCC implementation was selected because it was less complicated than the ASO version and the required input data was easier to obtain. The details of the existing models and the COSDIF procedure were obtained from the personnel at SPCC, ASO and the Operations Analysis division of the Fleet Material Support Office (FMSO).

NAVSUP personnel also requested that an unconstrained version of the VT model also be evaluated. For the VT model this meant (a) relaxing the current upper bound on an item's depth, and (b) continuing to search for items on the variable threshold list which had lower unit costs than the residual budget.

Both the existing and proposed models were programmed in Fortran on the NPS IBM 3033 computer. Initial tests were conducted to determine if the NPS computer programs of the existing models were correct. Several changes were required as a consequence of discussions of results with FMSO before the programs were considered to be satisfactory.

1.2 PURPOSE

This report presents the details of the evaluations of the existing and proposed models using data from recent provisioning packages provided by SPCC and ASO. Seven of the packages provided by SPCC and the five packages provided by ASO were used in the evaluations of the proposed models.

1.3 PREVIEW

Chapter 2 reviews the detail of all of the models which were evaluated. Chapter 3 describes the details of the data provided by SPCC and ASO. Chapter 4 presents the performances of the models for each package.Chapter 5 discusses the results in Chapter 4. Chapter 6 presents a summary and conclusions. The appendices contain copies of the FORTRAN programs used to perform the reprovisionings and the SPCC and ASO input data formats.

2. THE MODELS

2.1 INTRODUCTION

This chapter presents an overview of the models used in the analyses. The models include the COSDIF, Variable Threshold (VT), unconstrained Variable Threshold (VTU), Straight Line, D52, Gross Effectiveness (G-E), and Mean Supply Response Time (MSRT). The overview for each model will include key assumptions, basic formulas, and a summary of the algorithmic steps.

2.2 COSDIF MODEL

As mentioned in Chapter 1, we will consider the SPCC version of the COSDIF model which is described in detail in Application D Operation 55 titled "System Stock Requirements for SPCC Provisioning" [6]. This model was one of the models used in the evaluation because Reference 5 requires it to be used if an alternative model has not been approved. Thus, it serves as a baseline for considering improvements. It is also important because it is the required model for generating the budget.

The first step in using this model is to determine the schedule of end item installations over the first year after the Material Support Date (MSD) and to use that to estimate the average number of end items to be supported over the whole year. This quantity is called the initial time-weighted average month's program ($TWAMP_I$). The expected first year's demand for each spare and repair part is then computed from the product of this average and the expected frequency of replacement associated with each part (called the "best replacement factor" or BRF).

In addition to the initial installation schedule, the expected final installed quantity of the end item is determined and is called the steady state TWAMP (denoted by $TWAMP_{SS}$). This quantity is used to compute the expected annual demand for each spare and repair part once all planned installations of the end item have been completed. This "steady state" annual demand is then used in the COSDIF formula to determine the range of parts to be stocked. The detailed formulas for computing the initial and steady state annual demands are presented in Appendix A of References 2 and 6.

The second step is to use the COSDIF formula to determine if an item will be used in computing the budget. The COSDIF formula can be found in Appendix B of Reference 1 and Appendix A of Reference 6 and will not be repeated here because of its length. Fundamentally, it attempts to compare the expected steady state costs of buying and maintaining an inventory of a given part over two years with the expected costs of not stocking the part, incurring a shortage cost whenever a unit is demanded and having to make spot buys to fill that demand. If it is more expensive to incur a shortage than to hold inventory, the COSDIF value is negative and the part qualifies for stockage as a "demand-based" item. Such an item can then be used in determining the budget.

The third step is to compute the depth of a demand-based item. First, the expected demand over the procurement lead time is computed as the product of the initial quarterly demand rate based on $TWAMP_I$ and the procurement lead time (PCLT) in quarters. An additional quarter's worth of expected demand is then added to provide a "procurement cycle/safety level" worth of extra protection [5]. For a repairable item the expected demand during procurement lead time plus one quarter is based on the attrition demand difference between the total expected demand for the item and that fraction of the demand satisfied by repaired units. These repaired units are not available to satisfy demand until after a depot turn-around time (DTAT).

This depth, in considering only the initial year's end item installation schedule, is less than if the installation schedule over PCLT plus one quarter were used to compute $TWAMP_I$. The authors of reference 5 decided that limiting $TWAMP_I$ to the first year's installation schedule would hedge against the buying of large inventories of parts which were later found to have much lower BRF's than were initially predicted by the designer and manufacturer.

The final step is to compute the budget. Separate budgets are determined for consumables and repairables. The budget consists of the total procurement costs for buying the depths of those items which qualify for stockage as demand-based plus the costs of buying one unit each of items which did not qualify as demand-based but have been identified as insurance items and numeric stockage objective (NSO) items. Insurance and NSO items have extremely small probabilities of being demanded but, if they are demanded, a shortage would create a severe degradation in combat readiness. In all of the models to be considered, the portion of the budget associated with insurance items and NSO's will be assumed to have been allocated as derived to those items and will be considered no further in this report. The demand-based portion of the budget will be allocated according to the specific model to be described below.

In conclusion, the COSDIF model provides both the "baseline" depths which can be compared to those of the models to follow as well as the budget constraints which must be satisfied by these models.

2.3 VARIABLE THRESHOLD MODEL

This model was developed by the Navy Fleet Material Support Office (FMSO) to allocate the budget generated by the COSDIF model over a broader range of items than the COSDIF model [6]. The model also uses specific demand probability distributions in computing the depths rather than just the expected demands over the time period for which protection is desired.

The first step of the model is to calculate the variable threshold value for each item i using the following formula:

$$V(i) = [1 - \exp(-D_{PCLTi})]/C_i$$

where D_{PCLTi} is the expected initial demand during $PCLT_i$ and C_i is the unit cost of the item. The items are then ranked from highest to lowest in V(i) value. The budget allocation begins with the item at the top of the list.

The depth of each item to be procured is based on the expected initial demand during PCLT and the assumed probability distribution for demand. The latter is determined based on the initial annual demand rate, D_A, according to the following rule:

$$\text{Demand distribution is} \begin{cases} \text{Poisson if } D_A \leq 1; \\ \text{negative binomial if } 1 < D_A < 20; \\ \text{normal if } D_A \geq 20. \end{cases}$$

For repairables, D_A is the initial annual attrition rate plus the expected demand during depot repair turn-around-time (DTAT).

The first step in determining the depth of item i is to compute its risk value using the following formula:

$$\text{Risk}(i) = \frac{IC_i}{IC_i + \lambda_i E_i}$$

where IC_i is the annual unit holding cost, λ_i is the unit shortage cost, and E_i is a measure of the item's essentiality. This risk value corresponds to the probability of one or more shortages (backorders) occurring before the first replenishment buy is received into the wholesale system. That time interval is assumed to be a PCLT in length. The depth, R_i, is then the largest value of x_i, the item's actual demand during $PCLT_i$, for which the probability of x_i not exceeding R_i is greater than or equal to 1-Risk(i). Notationally, we want R_i to be the largest integer value of x_i such that

$$P(x_i \leq R_i) \geq 1 - \text{Risk}(i)$$

The difference, 1-Risk(i), can be considered as the desired "level of protection".

The value of R_i is then constrained to not exceed the expected initial demand during PCLT plus one quarter. R_i is also lower bounded by the expected initial demand during procurement lead time. The rounding rules are the next highest integer for the lower bound and a 0.5 rounding rule for the upper bound. At least one unit is stocked if there is sufficient budget available.

After the desired depth, R_i, had been determined, the cost to procure that depth, C_iR_i, is subtracted from the budget and the next item on the variable threshold list is considered. If an item is reached for which its unit cost, C_i, is larger than the remaining budget, the model allocates no depth to that or any other item below it on the list. If an item is reached for which C_i is less than the remaining budget but C_iR_i exceeds that remainder, the item is stocked to a depth which can be bought and the rest of the items on the list are not bought.

2.4 UNBOUNDED VARIABLE THRESHOLD MODEL

This model differs from the Variable Threshold in only two respects. The first is that there is no upper bound on the depth. The second is that the procedure described above for terminating allocation of the budget is relaxed. When an item on the ranked list has been reached for which its C_i value is larger than the remaining budget, that item is ignored and the search continues on down the list. In addition, if any item has a C_i value less than the remaining budget but C_iR_i exceeds the remaining budget then that item is stocked at the depth which can be bought. The budget remaining after this action is less than C_i but still may be sufficient to buy other items further down the list so the search continues.

2.5 STRAIGHT-LINE MODEL

The parameters needed for computing the COSDIF formula were not available from ASO packages so the development of the budget constraint as specified by Reference 5 was not possible. The budgets for the original provisionings of the ASO test packages were also not directly available except for the F/A-18 FLIR. They could be computed from the depths that were provided with the data. However, some of these depths were known to have been "adjusted" as a consequence of management decisions and thus budgets based on these depths would not be consistent over all the packages. Fortunately, discussions with ASO personnel indicated that the budgets for packages having 50 or fewer items were usually generated and implemented using a technique known as the "Straight-Line" method. This technique does not use the COSDIF formula to decide on the range of items. Instead, it assumes that any item will be stocked providing its expected demand during PCLT is at least one unit using a 0.5 rounding rule. It then follows the rest of the COSDIF model in computing the item depths and the associated budget. The depth is the expected demand over PCLT plus one quarter for each item. This depth is multiplied by the item's unit cost. The budget is then the sum of these products.

Because this model provides consistency of the budget generating process and is also the actual model used by ASO for provisioning small packages, it will be used as the "base-line" model for the analyses of all of the ASO packages.

2.6 D52 MODEL

The details of the D52 model as implemented by ASO are contained in Application D, Operation 52, "System Stock Requirements for ASO Provisioning" [7]. The version programmed by the author was a combination of "optimization" and "production" runs because the results of the original optimization runs were not available for any of the ASO packages. In particular, the Lagrangian parameter in the risk formula was not known. As a consequence, a bisection search technique such as ASO uses in an optimization run was needed to determine the "optimal" value of that parameter.

The risk formula is:

$$\mathrm{Risk}(i) = \frac{\theta C_i}{\theta C_i + \mu_i},$$

where μ_i is the expected demand over PCLT_i and θ is the Lagrangian parameter. ASO bounds this Risk between 0.05 and 0.5. Combining the risk formula with these bounds results in lower and upper bounds on θ which are:

$$\min_i \left\{\frac{\mu_1}{19C_i}\right\} \leq \Theta \leq \max_i \left\{\frac{\mu_i}{C_i}\right\}.$$

The search was therefore constrained to Θ values between these two values.

The algorithm associated with this search begins with Θ at its lower bound. The Risk is then computed for each item and is contrained to be between 0.05 and 0.5. The resulting risk value is used with the Poisson and normal probability distributions (Poisson if expected demand during PCLT is less than four units and normal if it is four or greater) to compute the depth of each item. The costs associated with buying all items at their respective depths are then computed and summed. If this sum is greater than the budget the risk and depth for each item is recomputed using a value for Θ which is the average of the upper and lower bound values (that is, it is "half way between" the bounds). It is not necessary to try Θ at its upper bound because that corresponds to a depth of μ_i which is less than the Straight-Line depth. Thus the budget constraint provided by the Straight-Line method would easily be satisfied.

As long as the budget is still exceeded, the next value selected for Θ will be half way between the upper bound and the latest value of Θ. If the budget is not exceeded, the next value of Θ will be half way between the lower bound and the latest value of Θ. D52 continues searching for new values of Θ and discarding those that result in the budget being exceeded and "halving the distance" between the two most recent Θ values, one of which results in the budget being exceeded and the other results in the budget not being used up. The process is terminated when (a) the budget consumed is within one percent of the budget constraint because that is the stopping rule that ASO uses in a D52 optimization run, or (b) the change in Θ is less than 0.000001. The latter rule terminated the computations for all packages except the F/A-18 FLIR.

2.7 GROSS EFFECTIVENESS MODEL

As was stated in Chapter 1, the goal of the Gross Effectiveness (G-E) model is to maximize the overall gross effectiveness of the items in a provisioning package for a given budget. The formula for gross effectiveness was presented in Reference 1 and is restated here.

$$G\text{-}E = 1 - \frac{\sum_{i=1}^{n} E_i \sum_{x_i = R_i + 1}^{n} (x_i - R_i) p_i(x_i)}{\sum_{i=1}^{n} E_i \, Z_i(T_i)},$$

where R_i is the number of units stocked of item i, x_i is the demand for the item during the interval of protection T_i, $p_i(x_i)$ is the probability that x_i will be demanded during the interval, E_i is the item's military essentiality, and $Z_i(T_i)$ is the expected demand over the protection interval. The probability distribution was assumed to be Poisson.

The protection interval was selected to be PCLT for ASO items since ASO's initial reorder point value for its replenishment model is the expected demand during PCLT. In constrast, the initial reorder point for SPCC is zero and will rise slowly as actual demands are observed. A protection interval value of PCLT plus one quarter was considered by NAVSUP personnel as reasonable for SPCC.

The technique used to solve for the optimal depths is marginal analysis. The procedure required that a ratio be formed for each item to describe the marginal rate of change of the objective function per marginal change the budget. The marginal change in the budget is merely C_i, the cost of increasing the depth of item i by one unit. The marginal change in the gross effectiveness requires that we determine a formula for the change in that function as the depth is changed by one unit. That change is equivalent to a change in the essentiality-weighted units short, or

$$E_i \sum_{x_i = R_i + 1}^{\infty} (x_i - R_i) \, p_i(x_i),$$

since the denominator of G-E is constant. The resulting change can be shown to be

$$- E_i \sum_{x_i = R_i + 1}^{\infty} p_i(x_i) = E_i[1 - \sum_{x=0}^{R_i} p_i(x_i] = E_i[1-P_i(R_i)]$$

Thus, the ratio which is used in the marginal analysis technique is

$$\frac{E_i[1 - p(R_i)]}{C_i} .$$

The marginal analysis begins with all R_i values set at 0. The first step towards increasing the R_i values is to set all R_i equal to 1 in the ratios and to identify that item having the smallest ratio value. This will be the first item to have its depth increased to one. The reason for selecting the minimum value is that minimizing the expected units short is equivalent to maximizing the gross effectiveness [2]. The next step is to increase this item's R_i value to 2 in its ratio and to compare this ratio value with the ratios of the items still having $R_i = 1$. That item now having the smallest ratio will have its depth increased by one unit and its new ratio will be computed based on R_i = (current depth + one unit). After each depth increase, another unit of an item is assumed to have been bought so the budget is decremented. In addition, after each increase in depth, that item's gross effectiveness is computed and its value is compared to a bound value of 0.9999. If the item's gross effectiveness has exceeded this bound value, the depth is reduced by one unit and is fixed at that value. It is important to emphasize that this bound is arbitrary but is needed to prevent stocking too much depth of any given item.

When the remaining budget is reduced to the level such that one more unit of the item having the "smallest" ratio cannot be bought, that item is dropped from any further ratio computations and its depth is fixed at its current value. The ratio computations continue for the subset of items having unit costs less than the remaining budget using the "nooks and crannies" subroutine.

Another constraint was imposed by the Navy. It was that the depth of an item which was stocked based on marginal analysis should be stocked to at least a depth equal to the expected demand during the protection period. This is equivalent to a risk constraint of 0.5. If, after the marginal analysis computations have been completed, only one item is stocked at a depth less than this constraint, the solution is acceptable as satisfying this constraint because that is the way the Variable Threshold model terminates. If, however, there are two or more items having depths less than this constraint, additional steps are required to insure the bound is satisfied. These steps first identify those items whose depths are at these lower bounds and fix them at these values. Then the budget is reduced by the price of these depths. The depths of the remaining items are returned to zero and the marginal analysis is rerun on these items. Several repetitions of this process may be required before a "Navy feasible" solution is obtained.

2.8 MEAN SUPPLY RESPONSE TIME MODEL

As was stated in Chapter 1, the goal of the MSRT model is to minimize the overall mean supply response time of the items in a provisioning package for a given budget. The formula for the mean supply response time was presented in Reference 2 and is restated here.

$$MSRT = \frac{\sum_{i=1}^{n} E_i Z_i(T_i) MSRT(R_i)}{\sum_{i=1}^{n} E_i Z_i(T_i)},$$

where the mean supply response time for item i is

$$MSRT_i(R_i) = k_i + \frac{TWUS_i(R_i)}{Z_i(T_i)}$$

and $TWUS_i(R_i)$ is the expected time-weighted units short when R_i units are stocked. The formula for the expected time-weighted units short when a Poisson distribution is assumed is

$$\text{TWUS}_i(R_i) = \frac{T_i}{2}\{H_i(R_i + 1)[Z_i(T_i) - 2R_i + \frac{R_i(R_i + 1)}{Z_i(T)}]$$

$$+ p_i(R_i)[(Z_i(T_i) - R_i)]\}.$$

Here $H_i(R_i)$ is the probability that the demand x_i during T_i will be greater than or equal to R_i. The value of k_i is the expected system response time if a unit is in stock somewhere in the system. Its value is quite small when compared to T_i and can therefore be ignored.

If an item is not stocked, the MSRT value will be half of the protection interval. This is a consequence of the assumptions of the model; namely, that after several demands a reorder point will be computed and a replenishment buy will be initiated for a quantity of more than one unit. All demands occurring during the protection interval must then wait to be satisfied by the replenishment buy. It follows that the expected waiting time for all of these demands will be half of the protection interval.

Again the optimization technique is marginal analysis. The numerator of the ratio is now the difference between the essentially-weighted time-weighted units short when R_{i-1} and R_i are stocked; namely,

$$\frac{E_i\{\text{TWUS}_i(R_{i-1}) - \text{TWUS}_i(R_i)\}}{C_i}.$$

The goal of minimizing time-weighted units short corresponds to minimizing MSRT. The algorithm for determining the optimal depths for this model is therefore the same as for the G-E model. The value of an item's MSRT, in days, is computed after its depth is incremented and compared to a bound of 0.001 days. This arbitrary bound prevents stocking too much of any item.

2.9 MARGINAL ANALYSIS BOUNDS

As described above, the optimization technique used for provisioning the ICP test packages by the G-E and MSRT models was marginal analysis.

Unfortunately, this technique may not always provide an optimal solution because it allocates the budget in an incremental and hence myoptic way. However, if the budget is determined using marginal analysis, then the solution obtained from this technique will provide the optimal solution [8].

The other technique that would be appropriate and would guarantee an optimal solution within the budget constraint is dynamic programming. Unfortunately, that technique would require large amounts of computer storage and computing time for packages in excess of twenty items [9].

Marginal analysis is a provider of fast solutions which are almost always optimal and it requires very little storage space. In addition, the "goodness" of a solution provided by marginal analysis can be quantified by determining a bound on the error between the solution and the true optimal solution. For example, let X^* be the vector of the true optimal stockage levels for a provisioning package and let X_m and X_{m+1} be the two sequential marginal analysis solutions where X_m satisfies the budget constraint and X_{m+1} exceeds it. The error and its bounds can be stated as follows:

$$\text{Error} = f(X_m) - f(X^*) \leq f(X_m) - f(X_{m+1}) = \text{Error Bound}$$

where $f(X)$ is the objective function of interest to be minimized; MSRT or the negative of G-E.

The marginal analysis algorithm used in computing solutions for the test packages was a modification of the "classical" procedure. Once the budget left became less than the max C_i then only those items were considered which had C_i less than or equal to the remaining budget. A bound for this modification can also be obtained. If we let X_0 be the "optimal" feasible solution resulting from this modification then it follows that $f(X_m) \geq f(X_0) \geq f(X^*)$ and we can now state

$$\text{Error} = f(X_0) - f(X^*) \leq f(X_0) - f(X_{m+1}) = \text{Error Bound}$$

In the presentation of the results of the test packages in Chapter 4 the error bounds will be shown for each solution derived by marginal analysis.

During the testing of the models with actual provisioning packages, FMSO personnel stated that the MSRT value for non-stocked items should be the procurement lead time since each demand would be filled only by a spot buy. This would be true if an item was never to become a stocked item. The MSRT model did not include this assumption. However, this "constraint" was inserted in the subroutine for computing the MSRT performance measure for each of the models for the test package results presented to NAVSUP in the spring of 1984. The constraint was dropped for the evaluations to be presented in Chapter 4 because of the need to compute error bounds for measuring the degree of optimality of the marginal analysis technique. Incorrect error bounds would result if the constraint had been left in.

2.10 MODEL PERFORMANCE MEASURES

After each model's stockage levels were computed for each test package, their aggregate values of Gross Effectiveness and Mean Supply Response Time were computed and used as the measures of performance. The G-E and MSRT formulas given above were used to compute these aggregate values. In addition, the remaining budget was determined for those model results which did not use up the budget to provide a third measure of performance.

3. THE TEST PACKAGES

3.1 INTRODUCTION

The test provisioning packages provided to NPS for evaluation of the proposed models included ten from SPCC and six from ASO. Of the ten from SPCC, review of the data indicated that seven had sufficient information to provide a good basis for comparison of current Navy models with the proposed models. All of the ASO packages were used. Summaries of the packages are presented in Tables 3.1 and 3.2. The last column contains the number of items of each cog in each package.

TABLE 3.1: SPCC Test Packages.

PCN	Nomenclature	Cog	Items
2WVO	TT-624B(V)/UG	1H	5
BEHA	Antenna	7G	25
5EZO	AN/SLQ-32(V)	1H	82
		7G	9
RDMA	AN/UYK-21	1H	38
		7H	85
T3HE	AN/SLQ-17AV2	1H	21
		7G	67
RDRA	MK-75-0 FOSS	1H	644
		7H	80
RDSA	MK-92-2 FOSS	1H	428
		7H	561

TABLE 3.2. ASO Test Packages.

PCC	Nomenclature	Cog	Items
PBV	P3 AN/ASH-33 SYSTEM	1R	48
		2R	28
PBT	EP3E RADAR SET CONTROL	1R	2
		2R	12
VAV	AWG25 A7E COMMAND LAUNCH OMPUTER	1R	3
		2R	16
V2J	A7E ELECTRO OPTICAL TEST SET	1R	4
		2R	28
ABR	F/A - 18 FLIR	1R	470
		2R	112

As the tables show, each package has a three- or four-digit code consisting of letters and numbers by which the system's data is identified for computer processing. This code is called the "provisioning control code" or PCC at ASO and the "provisioning control number" or PCN at SPCC. Each package is also identified by its nomenclature or description in English and numbers. The MK-75-0 and the MK-92-2 are shipboard gunfire control systems. The letters "FOSS" stand for "follow-on system stock" and indicate that this was a later additional provisioning of a system which was the result of a substantial increase in the population of the system (100% or more) beyond that originally provisioned. "FLIR" stands for "forward-looking infrared radar". F/A-18 is a fighter aircraft.

In the case of electronic equipment, the nomenclature sometimes follows the shorthand format of the Joint Electronics Type Designation System (JETDS). The JETDS coding system uses "AN/" to denote a "set" or end item. The letters which follow indicate what type of set the end item is. For example, the AN/UYK-21 is a general utility (U) data processing (Y) computer (K). The number 21 is assigned by the developing Hardware Systems Command (HSC) to distinguish this item from other end items which also carry the code UYK (such as the AN/UYK-7). If the item is a component of a set, then the code preceding the slash (/) indicates the nature of the component and its HSC number and the letters after the slash are its parent system. Thus the TT-624B(V)/UG is a tele-typewriter which is associated with a general (U) type of teletype set (G). The AN/SLQ-17AV2 and AN/SLQ-32(V) are shipboard electronic countermeasure equipments. The AN/ASH-33 is a flight recorder for the P3 aircraft.

The term "cog" means cognizance group and represents a class of items. The cogs listed in the tables include 1R (aviation consumables), 2R (aviation depot level repairables), 1H (ship and shore base consumables), 7H (ship and shore base depot level repairables under the technical control of the Naval Sea Systems Command (NAVSEA)), and 7G (depot level electronic repairables under the technical control of the Space and Naval Wareface Command (SPAWAR)). The 1R and 2R cog items are assigned to ASO for inventory management and are under the technical control of the Naval Air Systems Command (NAVAIR). The 1H, 7H, and 7G cog items are assigned to SPCC. The 1H cog items for the packages having 7G cog repairable items are under the technical control of SPAWAR. The 1H cog items for the packages having 7H cog repairable items are under the technical control of NAVSEA.

With the exception of the TT-624 package, the test packages contained both consumable and repairable items and, as was mentioned in Chapter 2, a separate budget constraint is developed for each of these classes of items. The Antenna package had 30 1H cog integrated circuit cards, all with identical data element values. The computed COSDIF value was $207.93 for each item. Therefore, no budget was generated and these items were not considered further.

3.2 SPCC DATA FORMATS

The data obtained from the ICPs was on tape and was in the standard format used for the provisioning computer runs at each ICP. However, the formats were different because of the differences in the procedures used to generate the budgets. The item data elements used by SPCC are listed in Appendix B. These are the required input data elements for running SPCC's

Application D Operation 55, "System Stock Requirements for SPCC Provisioning" [6]. Appendix B also lists the constant data elements. These are subdivided into Program Constants, which are used in the COSDIF formula, and Cog Constants, which are default values for certain item parameters as well as the shortage costs parameters needed by the COSDIF and variable threshold risk formulas. Appendix C lists the values of the Cog Constants for 1H, 7G, and 7H. The Program Constants' values and the standard deviation formula for the items in the SPCC test packages are contained in Appendix D.

The SPCC data record length was 400 columns and contained both the item input data elements as well as the output from the original provisioning computations. The first record on the tape for a package provided the details of the end item. Information stripped from that record for the evaluation tests included the PCN, the nomenclature, and the estimated total quantity to be installed (presumably the end item's $TWAMP_{SS}$ value). No $TWAMP_{I}$ was given in this record for any of the end items from SPCC. The rest of the records described the repair parts making up the end item. These records were also 400 columns in length. The columns stripped from these records included those corresponding to data elements 1, 2, 4-17, 19, 20 and 25 of Appendix B. Records 16 and 17 are described in Appendix B as being TWAMPSS and TWAMPI for each item. In reality, they were found to be the product of the best replacement factor and the end item's $TWAMP_{SS}$ and $TWAMP_{I}$, respectively. In addition, there were columns containing the item's nomenclature, quantity per application, the expected lead time demand, the unit of issue and the Variable Threshold depth that SPCC has computed. These were also stripped. The Variable Threshold values were to provide a comparison with these values to be computed by the Naval Postgraduate School's emulations of the SPCC procedure. A data set was constructed from the stripped data.

A Fortran program was then written to give a preview of the data in a "user friendly" format. A sample of the printout provided by this program is contained in Appendix F. Several aspects of the data were identified from these printouts. For example, the $TWAMP_{I}$ and $TWAMP_{SS}$ values for each item were found to contain the units of application (the number of units of the item used in the end item). A check was also made to see if there were inconsistencies in these data. In particular, the ratio between $TWAMP_I$ and $TWAMP_{SS}$ was checked. That ratio should not exceed 1.0 and should be consistent between items which are in the same package. These ratios for the SPCC items are presented in Table 3.3.

Clearly, the AN/SLQ-32 does not conform to the logical expectation for the ratio; namely that $TWAMP_I$ should not exceed $TWAMP_{SS}$. In addition, the AN/UYK-21 lacked consistency. The reasons for such "unusual" behavior were not obvious to SPCC personnel. Fortunately, the impact of these discrepancies on the evaluations was minimal and could be ignored. In addition, the end item "$TWAMP_{SS}$" values from the first data record for several packages appeared to be unrelated to any piece-part $TWAMP_{SS}$ and therefore only the latter values were used in any computations.

TABLE 3.3: The $TWAMP_I/TWAMP_{SS}$ Ratios for SPCC Items.

PCN	Nomenclature	Cog	Ratio
2WVO	TT-624B(V)/UG	1H	1.0
BEHA	Antenna	7G	1.0
5EZO	AN/SLQ-32(V)	1H	1.04
		7G	1.04
RDMA	AN/UYK-21	1H	0.01 to 0.48
		7H	0.06 to 0.50
T3HE	AN/SLQ-17AV2	1H	1.0
		7G	1.0
RDRA	MK-75-0 FOSS	1H	0.8
		7H	0.8
RDSA	MK-92-2 FOSS	1H	0.75
		7H	0.75

3.3 ASO DATA FORMATS

The data elements used in running ASO's Application D, Operation 52 (D52) [7], are listed in Appendix E. The tape record length was 130 columns. The format is known as Q17HY1 (formerly J14HX1) at ASO. The data elements of interest which were stripped from this tape included elements 1, 2, 3, 5-11, 14-18, 20 and 21. Output data elements from the ASO production runs of D52 were also provided on a second tape. The depths computed using D52, the costs of these depths, and the average demand during PCLT were stripped from this tape to provide a comparison with those values to be computed by the NPS emulation of D52. ASO also provided the maintenance cycle and rework cycle values which were used to generate the data for each package. The relevant ASO data was aggregated into a data set.

The values of $TWAMP_I$ and $TWAMP_{SS}$ for ASO items were not available because the approach at ASO is to-develop demands based on "program-related" data. More specifically, the demand is based on anticipated maintenance actions for an aircraft. Combining the $TWAMP_I$ with the associated planned flying hours during the initial twelve months after Material Support Date (MSD) gives an estimate of the total flying hours for all aircraft expected to be flying during that time. This is then divided by the expected 100 hours of flying time between maintenances to determine the number of expected maintenance actions during the initial twelve months. For historical reasons this value is then multiplied by 1.5 to create the expected number of maintenance actions over an assumed historical lead time of 18 months. In addition, an estimate is made of the expected total number of aircraft overhauls over this same 18 months.

Each end item is then subdivided into its repairable components and each component is further subdivided down to the piece parts level. The demand for the latter can then be related to the maintenance actions and overhauls.

During aircraft overhauls, concurrent rework of repairable components may be done. In addition, at the time of the 100 hours maintenance actions, repairable components may be replaced because of failure and sent to a depot for component rework (overhaul).

The ASO formula for computing the expected demand of a consumable item over its PCLT is:

Total Expected Demand = Maintenance Demand over PCLT
+ Overhaul Demand over PCLT
+ Concurrent Reworks over PCLT;

= MC*PCLT*TOTP*B022/6
+ RMC*PCLT*F/JPOP*B022A/6
+ RWK*PCLT*CONCP*B022A/6

where MC = Total maintenance cycles over 18 months;
RMC = Total rework maintenance cycles over 18 months;
RWK = Total overhaul cycles over 18 months;
TOTP = Total number of units of the item in the end item;
F/JPOP = Total number of units of the item in those components which may need rework at the end of a maintenance cycle;
CONCP = Total number of units of the item in those components which may need concurrent rework during end item overhaul;
B022 = Probability of the item being replaced in a maintenance action;
B022A = Probability of the part being replaced in a component overhaul;
PCLT = Item procurement lead time in quarters.

The divisor of 6 is to convert the 18-month "cycle" values to a quarterly rate.

The formula for the demand for a repairable item is less complex. The formula is fundamentally the attrition demand over the item's procurement lead time.

Total Expected Demand = Maintenance Demand over PCLT
- Reworks over PCLT

= MC*PCLT*TOTP*B022/6
- RMC*PCLT*TOTP*B022B*F009/6

where MC = Total maintenance cycles over 18 months;
RMC = Total rework maintenance cycles over 18 months;
TOTP = Total number of units of a part in the end item;
B022 = Probability of the item being replaced in a maintenance action;
B022B = Probability of the carcass of the part being returned for overhaul;
F009 = Probability of the carcass being successfully repaired;
PCLT = Item procurement lead time in quarters.

In the few cases where an end item is not program related, minor modifications to the above formulas are made. B022 is replaced by F001 which is the probability that the item will be removed during a maintenance action at the organizational level. B022A is replaced by F003 which is the probability that the item will be replaced during overhaul. Obviously, the MC, RMC, and RWK values must still be estimated using the $TWAMP_I$ and some idea of how often an end item will need preventative and corrective maintenance. Some information can be obtained from the design engineers. Some notion of total operating hours over the initial year is also needed.

The maintenance and rework cycles for the A30 packages are presented in Table 3.4. The V2J package was not program related.

TABLE 3.4. Maintenance and Rework Cycles for ASO packages.

PCC	Nomenclature	MC	RMC	RWK
PBV	P3 AN/ASH-33 SYSTEM	786	707	0
PBT	EP3E RADAR SET CONTROL	90	79	0
VAV	AW25 A 7E COMMAND LAUNCH COMPUTER	477	408	0
V2J	A7E ELECTRO OPTICAL TEST SET	14	11	0
ABR	F/A-18 FLIR	385	317	52

4. MODEL PERFORMANCE WITH SPCC AND ASO DATA

4.1 INTRODUCTION

The performances of the current and proposed provisioning models for the SPCC and ASO data packages are presented in Tables 4.1 through 4.13. Each table is subdivided to show the performances for consumables and repairables separately. This is done because their budgets are generated separately by both SPCC and ASO. The budgets computed for each type of spare part are shown at the top of each subdivision along with the cog and the number of items of that cog in the provisioning package. These budgets are only for the non-insurance items.

The models are evaluated, as described in Chapter 2, by computing their aggregate gross effectiveness (G-E) and mean supply response time (MSRT) values using only non-insurance items. The values of G-E are in units of percent and the values of MSRT are in units of days. In addition to showing the values of these performance measures, the amount of money remaining in the provisioning budget is also given to provide a measure of how well each model used up the budget.

Finally, the tables provide an indication of how well the technique of marginal analysis performs in providing approximately optimal solutions for the G-E and MSRT models. The concept of bounds on the "goodness" of the marginal analysis solutions, as described in section 9 of Chapter 2, is used in this evaluation. As will be seen, there are cases where the marginal analysis technique does not provide very good solutions. Fortunately, the true optimal solutions can be inferred from the performance of the models used to generate the budget.

The individual item depths will not be shown because the number of items totaled 2768 when all packages were considered and that level of detail is not needed for model comparisons. However, printouts of the individual items, depths for each package were provided to SPCC and ASO personnel for their use in making detailed comparisons between the models.

Chapter 5 provides a discussion of these tables and the conclusions which can be reached.

4.2 THE PERFORMANCE TABLES

Table 4.1: 2WVO; TT-624B(V)/UG

Cog: 1H   5 Items   Budget: $90.00

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	38.84	73.56	4.64	8.35 days
G-E	38.84	73.56	4.68	7.32 %
VTU	62.26	66.34	5.98	-
VT	44.00	65.26	18.66	-
COSDIF	44.43	69.31	0	-

Table 4.2: BEHA; ANTENNA

Cog: 1H   30 Items   Budget: No Budget

Cog: 7G   25 Items   Budget: $739,064

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	39.56	76.22	2717	4.55 days
G-E	41.99	76.26	1228	0.52 %
VTU	42.30	73.50	4649	-
VT	42.43	73.46	7941	-
COSDIF	85.71	61.69	0	-

Table 4.3: 5EZO; AN/SLQ-32(V)

Cog: 1H 82 Items Budget: $120,234

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	0.85	98.80	0.20	0.05 days
G-E	0.90	98.91	2.07	0.01 %
VTU	2.14	98.32	665.44	-
VT	5.38	93.21	10578	-
COSDIF	6.71	92.93	0	-

Cog: 7G 9 Items Budget: $414,160

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	21.49	87.04	1490	2.31 days
G-E	22.09	88.10	1980	0.60 %
VTU	31.46	79.31	2020	-
VT	31.46	79.31	2020	-
COSDIF	53.89	75.95	0	-

Table 4.4: RDMA; AN/UYK-21

Cog: 1H 38 Items Budget: $342,770

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	6.10	95.80	25	0.33 days
G-E	9.11	96.95	288	0.91 %
VTU	19.70	83.03	63559	-
VT	22.90	80.53	64569	-
COSDIF	27.56	83.13	0	-

Cog: 7H 85 Items Budget: $3,325,554

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	3.70	95.10	39	0.32 days
MSRT(2)	3.90	94.84	9	-
G-E	4.80	95.68	67	0.09%
G-EB(2)	4.81	95.57	7	-
VTU	5.43	94.89	1509	-
VT	8.42	91.28	56450	-
COSDIF	9.46	91.75	0	-

Table 4.5: T3HE; AN/SLQ-17AV2

Cog: 1H   21 Items   Budget: $168,806

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	1[illegible].15	89.68	32	0.16 days
MSRTB(4)	15.25	85.84	22	-
G-E	18.62	91.76	61	0.40 %
G-EB(2)	18.40	91.52	13	-
VTU	20.13	91.03	123	-
VT	15.85	88.43	2212	-
COSDIF	21.35	87.18	0	-

Cog: 7G   67 Items   Budget: $3,019,552

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	7.14	94.99	65	0.31 days
MSRT(4)	7.80	94.45	386	-
G-E	11.68	95.92	156	0.19 %
VTU	11.18	91.68	19579	-
VT	15.12	88.94	10804	-
COSDIF	19.95	87.33	0	-

Table 4.6: RDRA; MK-75-FOSS

Cog: 1H 644 Items Budget: $950,294

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	3.34	98.40	0.08	0.04 days
MSRTB(11)	4.22	97.87	0.01	-
G-E	4.07	98.82	0.38	0.00%
G-EB(3)	3.97	98.70	0.28	-
VTU	7.01	98.30	181.58	-
VT	8.20	94.82	1768	-
COSDIF	8.36	94.80	0	-

Cog: 7H 80 Items Budget: $1,206,224

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	44.11	83.76	50	0.30 days
MSRTB(5)	58.64	81.35	31	-
G-E	49.50	85.22	58	0.17 %
G-EB(5)	56.32	81.72	15	-
VTU	56.21	83.99	4335	-
VT	62.19	79.62	3005	-
COSDIF	80.54	75.77	0	-

Table 4.7: RDSA; MK-92-2 FOSS

Cog: 1H 428 Items Budget: $2,544,739

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	1.82	97.90	2	0.03 days
G-E	1.92	98.13	14	0.03%
VTU	5.85	96.09	16204	-
VT	18.97	87.45	68874	-
COSDIF	50.67	79.55	0	-

Cog: 7H 561 Items Budget: $6,426,262

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	17.55	90.88	32	0.05 days
MSRTB(5)	30.76	84.98	6	-
G-E	28.04	92.03	31	0.04 %
G-EB(4)	27.89	86.88	57	-
VTU	24.09	88.99	2073	-
VT	36.82	82.72	19792	-
COSDIF	59.10	76.99	0	-

Table 4.8: PBV; P3 AN/ASH-33 System

Cog: 1R 48 Items Budget: $18,727

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	4.36	96.12	0.67	0.44 days
G-E	5.04	96.23	3.32	0.40%
D52	9.45	91.65	123	-
S-L	12.30	87.66	0	-

Cog: 2R 28 Items Budget: $51,732

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	54.93	70.30	182	0.87 days
G-E	56.32	69.87	106	1.02%
D52	142.12	30.05	37197	-
S-L	121.08	36.94	0	-

Table 4.9: PBT; EP3E Radar Set Control

Cog: 1R 2 Items Budget: $3,498

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	53.00	72.39	0	20.40 days
G-E	143.78	47.30	798	35.16%
D52	53.00	72.39	0	-
S-L	53.00	72.39	0	-

Cog: 2R 12 Items Budget: $75,000

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	96.33	70.42	243	64.11 days
G-E	96.35	70.41	1743	16.29%
D52	180.77	39.84	63169	-
S-L	232.28	20.51	0	-

Table 4.10: VAV; AWG25 A7E Command Launch Computer

Cog: 1R 3 Items No Budget

Cog: 2R 16 Items Budget: $466,452

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	18.95	91.74	2220	12.11 days
G-E	20.16	92.25	1902	0.07%
D52	25.35	89.82	24911	-
S-L	49.58	72.03	0	-

Table 4.11: V2J; A7E Electro-Optical Test Set

Cog: 1R 4 Items Budget: $3,045

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	71.30	63.56	1155	59.26 days
G-E	71.32	63.52	1770	27.03%
D52	87.24	50.92	2715	-
S-L	61.34	61.36	0	-

Cog: 2R 28 Items Budget: $13,392

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	105.58	46.08	66	20.77 days
G-E	136.51	46.20	74	10.58%
D52	151.05	30.12	6591	-
S-L	89.09	53.57	0	-

Table 4.12: ABR; F/A-18 FLIR

Cog: 1R 470 Items Budget: $1,445,610

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	1.27	98.50	0.65	0.04 days
MSRTB(2)	1.39	98.40	0.05	-
G-E	1.56	98.87	9.24	0.00 %
G-EB(2)	1.59	98.85	6.66	-
D52	4.96	96.88	8591	-
S-L	6.53	94.06	0	-

Cog: 2R 112 Items Budget: $26,563,416

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	9.15	95.07	192	0.61 days
G-E	10.44	95.38	1559	0.23%
D52	36.17	87.60	555433	-
S-L	46.02	81.52	0	-

Table 4.13: ABR; F/A-18 FLIR Using Contractor Data

Cog: 1R 470 Items Budget: $1,190,302

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	2.58	97.46	0.53	0.01 days
MSRTB(3)	3.55	96.36	0.83	-
G-E	3.03	97.92	3.95	0.02%
G-EB(2)	3.31	97.60	1.85	-
D52	8.46	93.57	0	-

Cog: 2R 112 Items Budget: $24,051,201

Model	Performance		Budget Left($)	Error Bound
	MSRT(days)	G-E(%)		
MSRT	13.04	93.19	405.81	0.27 days
G-E	15.24	93.75	1652	0.44%
D52	38.85	85.87	0	-

5. EVALUATION OF MODEL PERFORMANCE

5.1 INTRODUCTION

The purpose of this chapter is to evaluate the performance results presented in Tables 4.1 through 4.13. The chapter begins by examining the impact of the generated budgets including how well each model used up its budget. The chapter then addresses how well the MSRT and G-E models perform and how good the technique of marginal analysis is at providing optimal solutions for these models.

5.2 BUDGET CONSTRAINT

As explained in Chapter 2, the budget constraints for the SPCC and ASO data packages were generated using the DODINST 4140.42 specifications [5] (denoted by COSDIF in the tables) and the Straight-Line method (denoted by S-L), respectively. The S-L method considers all items and the budget is based on the expected demands over PCLT plus one quarter. Table 5.1 lists the ASO packages, the total number of non-insurance items in each package, and the number of those that had an expected demand of one or more units over PCLT plus one quarter using a 0.5 rounding rule.

Table 5.1: Number of Items Generating the Straight-Line Budget

PCC	COG	TOTAL NUMBER	NUMBER USED IN BUDGET	PERCENT OF TOTAL
PBV	1R	48	43	89.6
PBV	2R	24	3	12.5
PBT	1R	2	2	100.0
PBT	2R	12	1	8.3
VAV	1R	3	0	0.0
VAV	2R	16	7	43.8
V2J	1R	3	2	66.7
V2J	2R	27	4	14.8
ABR	1R	451	281	62.3
ABR	2R	107	11	10.3

The COSDIF procedure selects item depths to generate the budget in the same way as the S-L method. All items which are expected to have an average annual steady-state demand of 12 or more units are included. For the rest of the items, the COSDIF range criterion must be applied first. Items passing this test tend to have anticipated steady state demand greater than 2 to 3 per year depending on the cog [10]. Table 5.2 presents information comparable to Table 5.1 for the SPCC packages. There were no insurance items in the SPCC packages.

Table 5.2: Number of Items Generating the COSDIF Budget.

PCN	COG	TOTAL NUMBER	NUMBER USED IN BUDGET	PERCENT OF TOTAL
BEHA	1H	30	0	0.0
BEHA	7G	25	4	16.0
2WVO	1H	5	2	40.0
5EZO	1H	82	74	90.2
5EZO	7G	9	2	22.2
RDMA	1H	38	17	44.7
RDMA	7H	85	78	91.8
T3HE	1H	21	11	52.4
T3HE	7G	67	64	95.5
RDRA	1H	644	532	82.6
RDRA	7H	80	62	77.5
RDSA	1H	428	103	24.0
RDSA	7H	561	427	76.1

When Tables 5.1 and 5.2 are compared with Tables 4.1 through 4.12, some correlation can be observed between the percent of items used to generate the budget and the performance of all of the models for large packages (more than 40 items). For those having a large percentage of items (80% or more) generating the budget, the MSRT values were 12 days or less and the G-E values exceeded 85%. These packages include 5EZO/1H, RDMA/7H, RDRA/1H, and PBV/1R. T3HE/7G had G-E values exceeding 85% but the MSRT value for the COSDIF model was almost 20 days. The RDRA/7H and RDSA/7H packages had G-E values above 75% but MSRT values increased substantially; the lowest values for MSRT were 44.1 and 17.6 days, respectively. Finally, although ABR/1R had only 62% of its items generating the budget, it had very high G-E values (94 to 99%) and very low MSRT values (1.27 to 6.93 days). For the remainder of the large packages, the percent of items generating the budget was less than 50%. Both RDSA/1H and ABR/2R had G-E values of 80% or more and MSRT values less than 51 days.

The medium size packages (15 to 39 items) all had less than 53% of the items generating the budget. The SPCC packages showed consistent reduction in performance as the percent of items decreased; T3HE/1H was best (52.4%), RDMA/1H was next (44.7), and BEHA/7G was worst (16%). For the ASO items, a similar result was observed; VAV/2R was best (43.8%) and PBV/2R and V2J/2R were comparable at 12.5% (3 items out of 24) and 14.8% (4 items out of 27), respectively.

The small packages (2 to 14 items) were inconsistent. Of the two small SPCC packages, 5EZO/7G showed better performances than 2WVO/1H. In both cases, only two items were used to generate the budget. Apparently 5EZO/7G, having nine items to consider, allowed more freedom to improve performance than did 2WVO/1H with only five items. The two small ASO packages did show consistency. PBT/1R with only two items, both used to generate the budget, showed better performances (except for the G-E model) than did V2J/1R having two of its four items generating the budget.

The repairable budgets were larger than the consumable budgets for all packages. This is because the procurement prices for repairable items are, on the average, much larger than those for consumable items. The difference is emphasized by the ABR and RDRA packages. Table 5.1 shows that the number of items used to generate the ABR/1R budget was 281 while only eleven items were used to generate the ABR/2R budget. The budgets were $1.45 million and $26.56 million, respectively (see Table 4.12). Table 5.2 shows that the number of items used to generate the RDRA/1H budget was 532 while only 62 items generated the RDRA/7H budget. Table 4.6 gives the respective budgets as $0.95 million and $1.21 million.

The budgets generated by the COSDIF procedure for SPCC's packages did not appear to impose severe constraints on any model. All G-E values were at least 60% and MSRT values were less than 65 days except in two cases where the COSDIF model gave 81 and 86 days. In addition, the G-E values tended to increase and the MSRT values tended to decrease with increasing package size. This suggests that the severity of the budget constraint decreased as the package size increased. This may be because the percentage of items used to generate the budget tended to increase with package size.

Finally, the expected demand during the first year also affects the performance. 5EZ0/1H and RDRA/1H had higher expected demands, based on a per item average, than did the other SPCC packages.

The ASO budget generated by the straight-line method is strictly dependent on mean demand during PCLT plus one quarter and this demand is dependent on the number of maintenance cycles expected over the first 18 months after the material support data. The cost of an item is not considered. As Table 3.4 shows, the PBT and V2J packages had much lower numbers of maintenance cycles than the other ASO packages. As a consequence, very few PBT and V2J items were used to develop the budget (see Table 5.1). The computer printouts for the S-L budget showed those items as having depths of only one unit. The effectiveness values of these packages tended to be lower than the respective cog groups of the other three packages. Their MSRT values also tended to be larger.

One final check was made to see how close the depths from the D52 output tapes matched the S-L depths. It was discovered that the cost of what was reported as actually bought tended to exceed the S-L budget for small packages and to be less than the S-L budget for large packages. Table 5.4 shows the comparison between the S-L budget and the budget needed to buy the depths listed on the D52 output tapes.

Table 5.4: The S-L Budget and the Actual Budget.

PCC/COG	TOTAL NUMBER	S-L BUDGET	ACTUAL BUDGET
PBV/1R	48	$ 18,727	$ 14,463
PBV/2R	24	51,732	134,647
PBT/1R	2	3,498	3,498
PBT/2R	12	75,000	97,654
VAV/1R	3	0	15,951
VAV/2R	16	466,452	373,725
V2J/1R	3	3,045	0
V2J/2R	27	13,392	6,276
ABR/1R	451	1,445,610	1,190,302
ABR/2R	107	26,563,416	24,051,201

These results suggest that when the S-L method is used for small packages, it is only used as a "first cut" at the depths and management judgment then takes over and buys more.

5.3 BUDGET REMAINING

Since the COSDIF and S-L models were used to generate the budgets, their remaining budgets were obviously zero.

Tables 4.1 through 4.7 show large budgets left over for the Variable Threshold (VT) model. This is a consequence of the stopping rule used at SPCC. After ranking the items in descending order based on their variable threshold values (see Chapter 2), each item is then bought to a depth of the mean demand over procurement lead time plus the minimum of one additional quarter's expected demand or the safety stock (computed from the Risk formula). When an item is reached which has a unit cost which is more than the remaining budget or it cannot be bought to the depth described above, the depth bought is either zero or as many units as the budget will allow. Then no further items on the list are considered. The unbounded version of the Variable Threshold Model (VTU) allows items further down the list to be considered. As a consequence, the budget remaining for the VTU model is usually less than for the VT model. The VTU model also does not have an upper bound depth constraint of mean demand during procurement lead time plus one quarter.

The lower bound on the depth in the VT and VTU models was mean demand during procurement lead time using a 0.9999 rounding rule. This applies to all items considered except the last item bought; it can have a depth as low as one minimum replaceable unit.

Originally, the Variable Threshold model had a depth constraint for consumables of the expected demand over two years. That constraint was removed by SPCC after the author presented preliminary performance results for the models showing very large values for the remaining budget of those packages having lead times longer than two years.

Table 4.1 shows that the MSRT value of VTU is larger than the MSRT value of VT. Tables 4.5 and 4.6 show the remaining VTU budget to be greater than that of VT for the repairables (7G and 7H). In all three cases this is a consequence of relaxing the depth upper bound constraint mentioned above. The variable threshold rankings are, for the most part, inversely proportional to the item unit cost. Therefore, the less expensive items appear at the top of the ranking list and are bought first with VTU typically buying more depth for these items. The VTU model then has less money to spend on the expensive items near the bottom of the list.

The D52 model also shows a large budget remaining in Tables 4.8 through 4.12. The only exception is the PBT/1R package which consisted of only two items. The reason for the large residual is that when the bi-section search for the "optimal" value of the Lagrange multiplier terminates the items remaining under consideration are very expensive high demand items. Those items which are inexpensive high demand items are at their upper bound values corresponding to a D52 risk value of 0.05. The high cost low demand items are at their lower bounds corresponding to the D52 risk value of 0.5. It is important to note that these values *may* be zero because ASO uses the Poisson distribution for items having a mean demand during PCLT of less than 4.0 and the normal distribution otherwise. A depth of zero for a mean demand during PCLT of 0.67 or less corresponds to a risk value of 0.5 or less.

As can be seen from Tables 4.8 through 4.12, the D52 model does not always give better results than the S-L model. However, there is no reason to expect that it would necessarily be a better performer, especially for the performance measures of MSRT and gross effectiveness. The objective function which D52 seeks to optimize is a combination of the expected units short and the budget.

In practice, ASO uses D52 for large packages and the S-L model for small packages. The only large package was ABR. Its D52 depths as obtained by the contractor (determined using ASO's D54 and D52 programs) were also used to compute a different budget for both 1R and 2R cogs and to provide a comparison between the D52 emulation done by the author and that of ASO. Table 4.13 presents the results for this budget.

5.4 CONSTRAINED MSRT AND G-E MODELS

The MSRT and G-E models were run in both an unconstrained and a constrained mode. In the constrained mode, the same lower bounding rules as used by SPCC and ASO were applied. These bounds were the mean demand during procurement lead time, with a 0.9999 rounding rule for SPCC and a 0.5 rounding rule for ASO. Since these bounds may not be automatically attained by the unconstrained solutions (the results of the "first" iteration), all items having depths greater than zero and less than or equal to the appropriate lower bound were fixed at these lower bound values. The remaining items were then set back to zero and the optimization procedure was repeated for only these items. After each iteration, more items were fixed at their lower bounds. Finally, the iteration process was terminated when only one item was left which violated its lower bound (this is the same termination step used by the VT and VTU models). If these lower bounds were not automatically satisfied by the first iteration, the bounded models results are added as a separate line in the table and denoted by MSRTB(•) and G-EB(•) with the number of iterations needed to achieve the bounds shown in the parentheses. The largest number was eleven iterations for the MSRT model for RDRA/1H. This package also contained the largest number of items.

For those tables showing extra iterations being required to attain this lower bound, the constrained performance was always less than the unconstrained performance. For example, for RDSA/7H, the unconstrained MSRT model achieved an MSRT value of 17.55 days while the constrained MSRT model achieved an MSRT value of 30.76 days. In that same table, the unconstrained G-E model attained a G-E value of 92.03% while the constrained version (which required three iterations) attained a G-E value of 86.88. The extent of the reduction in performance tended to be related to the number of extra iterations required. However, the number of extra iterations required did not appear to be a function of the size of the package.

5.5 NEW MODELS VERSUS CURRENT MODELS

The performances of the MSRT and G-E models were better for all of the packages than the Variable Threshold model currently in use at SPCC. The MSRT and G-E models performed better for all but one package than the D52 currently used at ASO whether the budget was generated by the S-L method or D52. The exception was the G-E performance for PBT/1R in Table 4.9. The G-E model gave a significantly inferior performance while the others gave the same performance as the S-L model. The reason for G-E's poor showing was because the marginal analysis technique did not give a good solution. In this case, the S-L method bought each of the two items to a depth of one unit. No other solution is better in this severely constrained case. Thus, in fact, the optimal G-E solution is identical to the solutions obtained by the other three models.

The MSRT and G-E models performed better than the S-L model for all ASO packages except PBT/1R (mentioned above) and the entire V2J package (see Table 4.11). The poor results for the V2J package provide another example of the marginal analysis technique giving poor solutions for the MSRT and G-E models. As Table 5.1 shows, only two items generated the 1R budget (their depths were one unit each) and only four items generated the 2R budget (their depths were also one unit each). As with the PBT/1R budget, the optimal solutions for the V2J/1R and 2R packages are those obtained by the S-L method. This would have been the solution obtained by the MSRT and G-E models if they had been solved using an optimization technique such as dynamic programming. Unfortunately, applying dynamic programming to the 2R package would have created a problem in both computer storage space required and running time because there were 27 non-insurance items in the package.

As was mentioned in Chapter 1, the criterion selected by NAVSUP for accepting new models was that at least a five percent improvement over the existing models (VT for SPCC and D52 or S-L for ASO) for the test packages. The unconstrained MSRT model gave MSRT values which were better than a five percent improvement for all packages except ABR/1R (Table 4.12) where it showed only a 3.7% improvement and PBT/1R (Table 4.9) and V2J where it showed no improvement. The constrained MSRT model also satisfied the 5%

criterion except for those packages just mentioned. The G-E model satisfied the criterion for all packages except for BEHA, RDMA/7H, T3HE/1H, RDRA/1H, PBT/1R, V2J, and ABR/1R packages. As was noted above, the poor results for PBT/1R and V2J were a consequence of the marginal analysis technique. The constrained G-E also met the criterion except for the same packages as the unconstrained model.

5.6 MARGINAL ANALYSIS ERROR BOUNDS

The marginal analysis technique does not guarantee an optimal solution unless the budget constraint corresponds to exactly the value needed by a marginal analysis solution [8]. The error bound described in Chapter 2 provides a measure of how well the marginal analysis technique performs for an arbitrary budget. Tables 4.1 through 4.13 show these error bounds for the unconstrained MSRT and G-E models. Such bounds cannot be obtained for the constrained versions because the marginal analysis technique is only part of the solution process.

The error bounds are very small for the large packages (40 or more items). As a consequence, the marginal analysis solutions are either optimal or very close to it. The error bounds are also small for those medium sized packages (15 to 39 items) having at least 40% of the items being used to generate the budget. As was discussed above, the marginal analysis technique performs very poorly for severe budget constraints. Thus, as the number of items used to generate the budget decreases in the medium size packages, the error bounds tend to increase. In addition, as the size of the package decreases, the percentage of items generating the budget needs to increase to keep the bounds small.

For the small packages (2 to 14 items), the budgets are typically rather severely constraining. However, the marginal analysis solution may come very close to using up the budget. This is the case for 2WVO/1H and PBT/1R packages. In particular, the PBT/1R package gives the optimal solution for the MSRT model. As a consequence, we need to also look at the additional budget needed to attain the next marginal solution. If it is large, then we can conclude that the current solution is very good. If it is small, then we have a poor solution from the marginal analysis procedure.

Consider first 2WVO/1H. The error bound is 8.35 days for the MSRT solution. The budget is $90.00. The infeasible solution used in computing the bound needed a budget of $92.68. Thus, for $2.68 additional budget, the MSRT model would have provided a reduction of 8.35 days in its computed MSRT value. However, if only $90.00 was available, it would be impossible to improve upon the MSRT solution obtained. Table 5.3 shows the data and solutions for this package.

Table 5.3: 2WVO/1H Model Solutions and Item Parameters

ITEM NO.	EXPECTED DEMAND OVER PCLT + 1	UNIT COST	COSDIF DEPTH	VT DEPTH	VTU DEPTH	G-E DEPTH	MSRT DEPTH	ERROR BOUND DEPTH (MSRT)
1	0.150	$0.04	0	1	3	3	4	2
2	0.292	1.30	0	1	3	4	4	2
3	3.510	10.00	5	5	8	6	6	5
4	1.462	20.00	2	1	0	1	1	2
5	0.466	175.00	0	0	0	0	0	0

When examining Table 5.3 and the solution associated with the error bound for a budget of $92.68, one's first reaction is to say that the extra $2.68 is made up of two units of items 1 and 2. However, if these two units are dropped, the solution which results is the same as the COSDIF model. Table 4.1 showed that the COSDIF model gave the worst MSRT value. The VT model gave a slightly better solution and emphasizes that ignoring items 1 and 2 is definitely not optimal. On the other hand, ignoring item 4 is not optimal either as the VTU model shows.

It is appropriate to also note that the G-E model gave the same performance as the MSRT model both for the MSRT and G-E measures. However, this was actually a consequence of rounding the performance values to two decimal places. The reason G-E gave item no. 1 only a depth of three was because of its G-E bound of 0.9999 for any individual item. The MSRT model did not have a bound on an item's G-E since it was concerned with optimizing

MSRT. As was mentioned earlier, that bound was set at 0.001 days for any item. If that bound had not been imposed, then the MSRT model would have spent the rest of the budget on items 1 and 2.

In conclusion, the marginal analysis technique gave a very good solution for the $90.00 budget. If, however, only $2.68 had been added, the MSRT value could have been reduced by 21%. The G-E error bound could have been attained with an additional $12.68. This would have increased the depth of item number 3 by one more than the MSRT error bound solution and increased the G-E performance by 10%. It may seem illogical that the G-E error bound solution has one more unit than the MSRT error bound. It should be recalled, however, that these bounds are the next step of the marginal analysis technique before resorting to the "nooks and crannies" subroutine (recall Section 2.10). What happened was that the preceding feasible solutions for the MSRT and G-E models were (2,2,4,2,0) and (2,2,6,1,0), respectively, and the next step created the error bounds by adding one more in each case to the depth of item no. 3.

BEHA/7G has an MSRT error bound which appears to be rather large. However, the additional budget needed to attain that bound is also rather large at $31,658. As a consequence, we can conclude that the MSRT solution is very close to being optimal. There were only two items whose unit costs were less than the budget remaining and both were stopped by the lower bound of 0.001 days for an item's MSRT value.

5EZO/7G has an MSRT error bound of 2.31 days. To attain this bound, the budget would have to be increased by $2000 which is less than 0.5% of the budget. In this particular case, the lowest unit cost is $5000. Thus, such an increase seems worth the 11% improvement in MSRT performance.

As was observed earlier, the MSRT solution for PBT/1R of one unit for each of the two items is optimal. The error bound is a consequence of adding one more unit to the least cost ($675) item. The benefit of selecting a larger budget is large; almost a 40% reduction in MSRT. The G-E solution was poor because marginal analysis bought two units of this least cost item first and then did not have enough budget to buy any other item whose cost was $2823. The G-E error bound solution corresponds to the same solution as the MSRT error bound.

The PBT/2R package is unique. In this case the S-L method selected one item which had a depth of one unit. It turned out to be the most expensive item in the package, having a unit cost of $75,000. The S-L model's performance was extremely poor. The MSRT and G-E solutions were much better but were very close and neither bought the expensive item. The G-E solution stopped before attaining the MSRT solution because of the G-E bound on individual items. To attain the MSRT error bound solution, the budget would need to be increased by $42,935. That solution would have spent the original $75,000 on one unit of the most expensive item and the rest would be spent on other items. This much larger budget does seem appropriate because of the substantial improvement gained in the MSRT model solution.

The MSRT solution for VAV/2R is very good in spite of the value of the error bound. The least cost item costs $3256 and the next least cost item costs $7146. To achieve the error bound, an additional $265,704 would be needed.

V2J/1R consisted of three non-insurance items. The depth computations for the G-E and MSRT models were stopped by their individual item bounds. Table 5.4 shows the depths for each current model and the MSRT model and its error bound. The V2J budget was quite severe at $3045. The marginal analysis technique did poorly for MSRT. The optimal solution was the S-L model solution. None of the other models achieved it because they all selected the lower cost items first. However, the MSRT error bound results could be obtained by adding another $375. For the gain in MSRT performance, it is well worth the additional expense.

Table 5.4: V2R/1R Solutions and Item Parameters

ITEM NO.	EXPECTED DEMAND OVER PCLT	UNIT COST	S-L DEPTH	D52 DEPTH	MSRT DEPTH	ERROR BOUND DEPTH (MSRT)
1	0.482	$2760	1	0	0	1
2	0.560	285	1	1	6	2
3	0.280	45	0	1	4	2

The V2J/2R package had a very constraining budget. The S-L method selected only four items out of 27 non-insurance items and these had depths of only one unit each. Again, the marginal analysis solutions gave poor solutions. The S-L model solution is optimal. The MSRT error bound solution requires an additional $525. It turns out that if the budget was increased by this much, then the G-E bound would also be attained.

In conclusion, we see that the marginal analysis technique gives poor solutions for small packages when the budget is generated by either the COSDIF or the S-L procedure. Both procedures generate very constraining budgets when the package size is small. The results, even if marginal analysis gives a good solution, are high MSRT values and low G-E values. The S-L procedure gives budgets which are more constraining than those from the COSDIF. In particular, the S-L method completely ignores costs of individual items. This is an important reason for discontinuing its use.

The resolution to the severe budget constraint problem for small packages is to establish an MSRT or G-E goal and determine the solution and budget needed simultaneously. The initial step could be to set the G-E goal at 85 percent in keeping with the RIMSTOP wholesale goal [3].

If large packages are being considered, then there is little harm for the near future from using the COSDIF procedure although it may create an excessive budget relative to reasonable MSRT or G-E goals if the packages are large.

5.7 MSRT VERSUS G-E

In spite of questions about optimality of the marginal analysis technique, the MSRT model provided a better MSRT value than did the G-E model and the G-E provided a better G-E value than did the MSRT model except for 2WVO/1H, PBV/2R, PBT/1R and PBT/2R. Actually, 2WVO/1H was not an exception for the MSRT model when the MSRT value is carried to three decimal places. The PBV/2R and PBT/2R results show the MSRT model performing better with respect to the MSRT objective but G-E does not perform better than MSRT with respect to the G-E objective although the difference is quite small. This was due to the use of marginal analysis. The problem with G-E and the PBT/1R package has already been discussed.

In deciding on which model to select, the MSRT model is preferred because of its emphasis on response time and the role it plays in the A_o formula. It also has the very nice property that the solutions also provide G-E values which are close to the optimal values provided by the G-E model.

6. SUMMARY AND CONCLUSIONS

6.1 SUMMARY

This report has presented performance evaluations for existing and proposed new models for determining the range and depth of repair parts to be initially stocked (provisioned) at the wholesale level of the Navy's supply system. The existing models are the Variable Threshold (VT) model of SPCC and the Straight-Line (S-L) and D52 models of ASO. The proposed models are the Mean Supply Response Time (MSRT) model and the Gross Effectiveness (G-E) model. The evaluations were conducted using actual data from seven systems that SPCC had previously provisioned and five systems that ASO had previously provisioned.

The measures of effectiveness were the aggregate (over all items in a system) mean supply response time and the aggregate gross effectiveness. The performances were constrained by procurement budgets. The SPCC budget constraint was generated using the COSDIF procedure specified by DODINST 4140.42. The ASO budget constraint was the Straight-Line method because all but one system had no information remaining which could be used to create a COSDIF budget (that procedure involves running the D54 and D52 programs of ASO). Separate budget constraints were generated for consumables and repairables in each system.

The criterion for a proposed model to be adopted by the Navy was that it must perform at least five percent better than the existing models. The MSRT model easily satisfied the criterion for ten of the twelve actual systems. The two remaining systems belonged to ASO and were so severely budget constrained that the proposed models gave the same result as the S-L and D52 models. The G-E model did not do as well in satisfying the criterion but did perform better than the existing models. Finally, the MSRT model had the nice property that it generated G-E values which are almost as high as those of the G-E model.

The optimization technique used for the proposed models was marginal analysis. It does not guarantee optimality unless the budget constraint is exactly equal to the budget associated with an iteration of the technique. It did provide fast, very good solutions for systems having 35 or more items in a cognizance group (consumable or repairable). Unfortunately, it performed poorly when there were few items in a cognizance group and when the budget was severely constraining. This corresponded to the two ASO systems discussed above.

6.2 CONCLUSIONS

The MSRT model is the preferred new model since it performed the best and is directly related to readiness through its role in the denominator of the operational availability formula [4]. It was formally accepted by the Navy in December 1984 as a consequence of the results described in this report and is now in the process of being programmed into the ADP systems of SPCC and ASO.

The marginal analysis technique gives good solutions for systems having 35 or more items. It is the only technique which can give such solutions quickly. Unfortunately, it does not perform well for small numbers of items, mostly because the COSDIF budget constraint tends to be quite severe. However, if a marginal analysis solution completely uses up the budget, regardless of the severity of the budget constraint, then the solution is optimal. Therefore, as long as the budget constraint must be generated by the COSDIF procedure, a reasonable approach to systems containing only a few items is would be to solve the MSRT model for the solution which is nearest the budget. This should preferably be the first solution which exceeds the budget. This solution could then be used to "adjust" the initial budget so that the solution could be bought.

The COSDIF procedure for generating the budget provides no connection between resources and readiness and should therefore be replaced with a technique which computes the budget needed to attain a specified readiness goal. The MSRT model can be used to create such a procedure. The first step would be to specify an MSRT goal. Then compute the solution to the MSRT model which satisfied this goal. The total cost to buy that solution is then the budget which should be requested from Congress. The marginal analysis technique can be easily used to find that first solution which satisfies the goal. To initiate the consideration of this approach by the Navy and DoD, each of the provisioning packages was analyzed for ten MSRT goals and the marginal analysis solution and its total cost (budget) were computed for each goal. Appendix G presents the curves for both the budget and marginal analysis MSRT values for each of these packages. The MSRT goals were 0.5, 1.0, 5.0, 10, 20, 30, 40, 60, 80, and 100 days. Smoothed curves connect these results for all but very small packages. The question which now remains is "what is an appropriate MSRT goal?"

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10. Navy Ships parts Control Center Internal Instruction 4400.30C, "Exploder Provisioning Manual", 15 September 1981.

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APPENDIX A

```
A.1     ****************************************************************
C *** PROGRAM TO TEST PROPOSED WHOLESALE PROVISIONING MODELS        ***
C *** USING SPCC PROVISIONING PACKAGES.                              ***
C ******************************************************************
C *** MAIN PROGRAM:
      INTEGER TWAMPI(1000),TWAMPS(1000),MRU(1000),NOBJ,STOP(1000)
      REAL B, DA(1000),PCLT(1000),TAT(1000),C(1000),R,RR(1000)
      REAL H,P1(1000),P2(1000),RISK,FL,PLT(1000),DT(1000),Z(1000)
      REAL TRF(1000),CR(1000),K0,Z1(1000),PPV,DATS,DATR,DTAT,DSUM(1000)
      REAL CT(1000),RSR(1000),E(1000),DSS(1000),PCN(4),EI(13)
      REAL MODGRE,MODMST,VAL1,VAL2,QA10,QA20,QA1,QA2
      REAL OV(2,1000), TOV(2),MR
      REAL*8 NAME1(3)/'COSDIF D', 'EPTH ', ' '/
      REAL*8 NAME2(3)/'VARIABLE',' THRESHO','LD MTHD'/
      REAL*8 NAME3(3)/'VAR THRS','HD UNBOU','NDED  '/
      REAL*8 NAME4(3)/'MAXIMIZE',' GROSS E','FFECT. '/
      REAL*8 NAME5(3)/'MINIMIZE',' MSRT',' '/
      INTEGER N,X(1000),NSO(1000),INS(1000),VTD(1000)
      INTEGER DEPTH(1000),DTI,INDEX(1000),NN1,NNN
      COMMON SN(1000,9),A(1000,17)
      EXTERNAL MODGRE,MODMST
C
C *** THE NEXT TWO PARAMETERS MUST BE SPECIFIED WHENEVER A NEW COG IS
C   * INTRODUCED; NRPR=0 MEANS A CONSUMABLE, NRPR=1 MEANS A REPAIRABLE.
C   * N=NO. OF ITEMS IN THE COG; THIS NUMBER IS PROVIDED BY THE OUTPUT
C   * OF THE PROGRAM WHICH WAS USED TO STRIP INFORMATION FROM THE SPCC
C   * TAPE (SEE CHAPTER 3) AND ESTABLISH THE DATA SET OF INPUT DATA FOR
C *** THIS PROGRAM. FOR EXAMPLE, THE MK-92-2 7H COG CONTAINED 561 ITEMS.
      N=561
      NRPR = 1
C *** THE NEXT PARAMETER CONTROLS WHETHER THE OPTIMIZATION PROCESS
C   * ALLOWS THE ICP LOWER BOUND CONSTRAINT (MEAN DEMAND DURING PROCURE-
C   * MENT LEADTIME).IF NNN=1 THEN THE LOWER BOUND IS IGNORED. IF
C   * NNN IS LARGE THE LOWER BOUNDING IS ALLOWED FOR AS MANY ITERATIONS
C   * AS NNN. NNN IS THEN USED TO PREVENT WASTING TIME ON AN INFEASIBLE
C   * PROBLEM WHEN THE BUDGET IS TOO SMALL.
C *** NN1 IS THE ITERATION COUNTER.
      NNN=15
      NN1=1
C *** NOBJ SPECIFIES THE NUMBER OF EVALUATION MEASURES TO BE USED FOR
C   * COMPARING MODELS. THIS WAS SET AT TWO SINCE THE MEAN SUPPLY
C   * RESPONSE TIME (MSRT) AND GROSS EFFECTIVENESS (G-E) WERE THE
C *** ONLY ONES USED.
      NOBJ=2
C *** THE DATA FOR EACH TEST PACKAGE IS READ FROM THE INPUT DATA SET.
C   * THE NOTATION CORRESPONDS TO THE SPCC NOTATION USED IN D55 FOR THE
C   * COSDIF COMPUTATIONS. PCN DENOTES THE PROVISIONING CONTROL NUMBER
C   * USED BY SPCC TO IDENTIFY EACH PACKAGE (SEE CHAPTER 4). SN DENOTES
C   * THE STOCK NUMBER. VTD WAS THE VARIABLE THRESHOLD DEPTH COMPUTED
C *** BY SPCC; ONLY USED IN INITIAL CHECKING OF THE MODVT ROUTINE.
```

```
      CI=8.0
      P=0.33
      READ(1,899)PCN,EI
  899 FORMAT(4A1,13A1)
      READ(1,890)COG,PI1,PI2,CRR,CRT,H
  890 FORMAT(A2,2F5.0,3F5.2)
      DO 2 I=1,N
       E(I)=0.5
       P2(I)=PI2
       CR(I)=CRR
       CT(I)=CRT
    2 CONTINUE
      READ(1,898)((SN(I,J),J=1,9),C(I),TRF(I),PLT(I),PCLT(I),
     *MRU(I),VTD(I),TWAMPI(I),TWAMPS(I),RSR(I),TAT(I),
     *NSO(I),INS(I),I=1,N)
  898 FORMAT(9A1,F10.2,F7.4,F4.1,F5.2,4X,I4,7X,3I5,F4.2,F4.1,2I4)
C *** A TABLE IS BEGUN DESCRIBING PACKAGE AND ITEM PARAMETER VALUES AS
C   * WELL THE COSDIF DEPTHS USED IN THE DEVELOPMENT OF THE BUDGET
C *** CONSTRAINT.
      WRITE(6,900)
      WRITE(6,901)EI,PCN,COG,N
      WRITE(6,902)
      WRITE(6,903)
      WRITE(6,904)
  900 FORMAT('1',///,'  ***********************************************',
     *'****************************************')
  901 FORMAT('0',1X,'***  END ITEM: ',13A1,18X,'PCN: ',4A1,8X,'COG: ',
     *A2,8X,'N: ',I4,2X,'***')
  902 FORMAT('0',' ***************************************************',
     *'****************************************')
  903 FORMAT('-',24X,'DEVELOPMENT OF THE COSDIF BUDGET CONSTRAINT')
  904 FORMAT('-','   NIIN          COSDIF   DEPTH   PROB-VAR      PCLT',
     * '      UNIT COST          BUDGET     INS? ')
C *** THE COSDIF BUDGET CONSTRAINT IS COMPUTED NEXT.
C --- ANNUAL DEMAND IS DETERMINED FIRST.
      DO 3 I=1,N
         P1(I)=AMAX1(PI1,H*C(I))
         DA(I)=TRF(I)*TWAMPI(I)
         DT(I)=TRF(I)*TWAMPS(I)
         DSS(I)=DT(I)*(1.-CR(I)*RSR(I))
    3 CONTINUE
      B=0.
C --- THEN COMPUTE CONDITIONAL PROBABILITIES & COST OF PROCUREMENTS.
      DO 40 I=1,N
      IF(INS(I).EQ.1)GO TO 37
C --- GET CONDITIONAL PROBABILITY DO/DT (DENOTED DODT).
          DTI=DT(I)+0.5
          IF(DTI.GE.1) GO TO 20
          DODT=0.7
          GO TO 30
   20     CONTINUE
          IF(DTI.GE.2) GO TO 22
          DODT=.59
          GO TO 30
```

```
   22     CONTINUE
          IF(DTI.GE.3) GO TO 23
          DODT=.49
          GO TO 30
   23     CONTINUE
          IF(DTI.GT.12) GO TO 30
          DODT=.32
   30     CONTINUE
C --- COMPUTE R ,THE REORDER POINT.
          R=DSS(I)*(PLT(I) + 1.)/4+(TAT(I)+CT(I))*CR(I)*RSR(I)*DT(I)/4
          IF(DTI.GT.12) GO TO 36
C --- DETERMINE CP AND Q-WILSON AND EVALUATE THE COSDIF EXPRESSION.
          QA1=SQRT(2.*DSS(I)*175./(H*C(I)))
          QA2=SQRT(2.*DSS(I)*535./(H*C(I)))
          QA10=AMAX1(QA1, 1.)
          QA20=AMAX1(QA2, 1.)
          VAL1=C(I)*(R+QA10)
          IF(VAL1.GT.8000.)GO TO 32
          CP=175.
          Q0=QA10
          GO TO 33
   32     CP=535.
          Q0=QA20
   33     AA=DODT*(CP+2.*H*C(I)*(R+Q0))
          VAL2=C(I)*QA10
          IF(VAL2.GE.8000.)GO TO 34
          AKSTAR=SQRT(2.*DSS(I)*175.*H*C(I))
          K0=AMAX1(AKSTAR,175.*DSS(I)+H*C(I)/2.)
          GO TO 35
   34     AKSTAR=SQRT(2.*DSS(I)*535.*H*C(I))
          K0=AMAX1(AKSTAR,535.*DSS(I)+H*C(I)/2.)
   35     BB=(1-DODT)*(K0+DT(I)*CI)
          CC=(1-DODT)*DT(I)*(450.+PLT(I)*P1(I)/4+C(I)*P)
C --- FINALLY THE VALUE OF COSDIF IS COMPUTED.
          CDIFF=AA+BB-CC
C --- THE NEXT STEP IS TO COMPUTE THE COSDIF BUDGET DEPTH FOR ITEMS
C --- HAVING NEGATIVE COSDIF VALUES OR DTI GREATER THEN 12.
   36     DATR=DA(I)*(1.-CR(I)*RSR(I))*(PCLT(I) + 1.0)/4
          DATS=DA(I)*(1.-CR(I)*RSR(I))*PCLT(I)/4
          DTAT=DA(I)*(CT(I)+TAT(I))*CR(I)*RSR(I)/4
          Z(I)=DATS+DTAT
          Z1(I)=DATR+DTAT
          DEPTH(I)=MAX1(Z1(I)+0.5,1.)
          IF(DTI.GT.12)GO TO 919
          IF(CDIFF.GE.0.)DEPTH(I)=0
          IF(CDIFF.GE.0.)GO TO 920
          IF(DEPTH(I).GE.1)GO TO 920
          IF(NSO(I).EQ.1)DEPTH(I)=MRU(I)
   37     IF(INS(I).EQ.1)DEPTH(I)=MRU(I)
   38     CDIFF=0.
   39     B=B+DEPTH(I)*C(I)
      WRITE(6,905)(SN(I,J),J=1,9),CDIFF,DEPTH(I),PPV,PCLT(I),
     *C(I),B,INS(I)
  905 FORMAT(' ',1X,9A1,F12.2,3X,I4,4X,F8.3,3X,F7.2,5X,
```

```
     *F9.2,3X,F12.2,3X,I4)
   40 CONTINUE
      WRITE(6,906)B
  906 FORMAT('-',19X,'TOTAL BUDGET FOR NON-INSURANCE ITEMS: $',F12.2)
C *******************************************************************
C    * THE BUDGET COMPUTATION HAS BEEN COMPLETED AND THE ITEMS USED
C    * IN ITS GENERATION HAVE BEEN IDENTIFIED. THE NEXT PART OF THIS
C    * PROGRAM CALLS EACH OF THE MODELS BEING COMPARED IN THE EVALUATION,
C    * COMPUTES THEIR ASSOCIATED DEPTHS, AND THEN CALLS THE EVALUATION
C    * ROUTINES TO DETERMINE THE RESULTING MSRT AND G-E VALUES. THE
C    * EVALUATION RESULTS ARE ALSO PRINTED.
C *******************************************************************
C *** COSDIF MODEL
      DO 50 I=1,N
      INDEX(I)=1
      STOP(I)=1
  50  X(I)=DEPTH(I)
      CALL PRTOUT(1,NAME1,0.0,0.0,N,E,X,Z,C,PCLT,OV,TOV,NOBJ,INDEX,STOP,
     *NN1,NNN,Z1)
C *** VARIABLE THRESHOLD MODEL ***
      CALL MODVT(N,B,X,BR,Z,Z1,C,E,H,P2,INS,NSO,VTD,MRU,INDEX,STOP)
      CALL PRTOUT(2,NAME2,BR,0.0,N,E,X,Z,C,PCLT,OV,TOV,NOBJ,INDEX,STOP,
     *NN1,NNN,Z1)
C *** VARIABLE THRESHOLD MODEL UNBOUNDED ***
      CALL MODVTU(N,B,X,BR,Z,Z1,C,E,H,P2,INS,NSO,VTD,MRU,INDEX,STOP)
      CALL PRTOUT(3,NAME3,BR,0.0,N,E,X,Z,C,PCLT,OV,TOV,NOBJ,INDEX,STOP,
     *NN1,NNN,Z1)
C *** MODEL TO MAXIMIZE GROSS EFFECTIVENESS ***
      CALL MODOPT(N,B,MODGRE,X,BR,Z,PCLT,C,E,RR,MR,INS,MRU,INDEX,STOP,
     *NN1,NNN,Z1)
      CALL PRTOUT(4,NAME4,BR,MR,N,E,X,Z,C,PCLT,OV,TOV,NOBJ,INDEX,STOP,
     *NN1,NNN,Z1)
C *** MODEL TO MINIMIZE MEAN SUPPLY RESPONSE TIME ***
      CALL MODOPT(N,B,MODMST,X,BR,Z,PCLT,C,E,RR,MR,INS,MRU,INDEX,STOP,
     *NN1,NNN,Z1)
      CALL PRTOUT(5,NAME5,BR,MR,N,E,X,Z,C,PCLT,OV,TOV,NOBJ,INDEX,STOP,
     *NN1,NNN,Z1)
      STOP
      END
C
      SUBROUTINE MODVT(N,B,X,BR,Z,Z1,C,E,H,P2,INS,NSO,VTD,MRU,
     *INDEX,STOP)
C *** SPCC'S VARIABLE THRESHOLD MODEL
      REAL V(1000),RISK(1000),Z(N),Z1(N),C(N),E(N),H,P2(N),BRL,BR
      INTEGER INDEX(N),STOP(N),Q,X(N),Y(1000),D,INS(N),NSO(N)
      INTEGER VTD(N),XX(1000),MRU(N),Q1,Q2,STOPSP
      INTEGER ZLB(1000),ZUB(1000)
      INTEGER*4 AY/'YES '/,AN/'NO  '/
      COMMON SN(1000,9),A(1000,17)
      CMIN=C(1)
C *** THE AVAILABLE BUDGET IS FIRST REDUCED BY INSURANCE AND NSO
C *** MINIMUMS.
      BRL=B
      STOPSP=0
```

```
      DO 10 I=1,N
      IF(INS(I).EQ.1)GO TO 8
      IF(NSO(I).EQ.1)GO TO 8
      XX(I)=0
      GO TO 10
    8 XX(I)=MRU(I)
   10 BRL=BRL-XX(I)*C(I)
      DO 20 I=1,N
         INDEX(I)=0
         STOP(I)=0
         IF(INS(I).EQ.1)GO TO 14
         ZLB(I)=MAX1(1.,(Z(I)+0.9999))
         ZUB(I)=MAX1(1.,(Z1(I)+0.5))
         IF(ZUB(I).LT.ZLB(I))ZUB(I)=ZLB(I)
         IF(Z(I).GT.120.)GO TO 12
         V(I)=(1-EXP(-Z(I)))/C(I)
         GO TO 13
   12    V(I)=1/C(I)
   13    RISK(I)=H*C(I)/(H*C(I)+P2(I)*E(I))
         Y(I)=NFX(Z(I),RISK(I))
         IF (C(I).LT.CMIN)CMIN=C(I)
         D=MAX0(Y(I),XX(I),ZLB(I))
         Y(I)=MIN0(D,ZUB(I))
         GO TO 15
   14    Y(I)=MRU(I)
   15    X(I)=0
         DO 16 J=1,9
   16    A(I,J)=SN(I,J)
         A(I,10)=INS(I)
         A(I,11)=V(I)
         A(I,12)=Y(I)-XX(I)
         A(I,13)=C(I)
         A(I,14)=NSO(I)
         A(I,15)=MRU(I)
         A(I,16)=VTD(I)
         A(I,17)=XX(I)
   20 CONTINUE
C *** THE CALL TO SORT IS ACTUALLY NOT NEEDED FOR SPCC DATA SINCE
C *** IT CAME SORTED ON THE TAPES THAT WAY.
C     CALL SORT(N)
      I=0
      BR=B
C *** THIS STEP ALLOCATES THE BUDGET AND WHEN IT HAS BEEN REDUCED TO
C *** ZERO SPECIFIES ZERO LEVELS FOR ALL OF THE REMAINING NIINS.
   21 IF(I.EQ.N) GO TO 30
      I=I+1
      Q1=A(I,12)
      Q2=BRL/C(I)
C *** THE NEXT STATEMENT INCLUDES THE CASE WHERE Q=0 IS POSSIBLE.
C *** SPCC IMPOSES A TERMINATION TO ALLOCATIONS (STOPSP=1) WHEN Q=0.
      IF(Q2.EQ.0)STOPSP=1
      Q=MIN0(Q1,Q2)
      X(I)=Q+A(I,17)
      NSO(I)=A(I,14)
```

```
      VTD(I)=A(I,16)
      IF(NSO(I).EQ.1)GO TO 22
      NSO(I)=AN
      GO TO 23
   22 NSO(I)=AY
C *** DECREMENT THE BUDGET IF FUNDS ARE LEFT OVER OR STOP.
   23 IF(STOPSP.EQ.1)X(I)=A(I,17)
      IF(STOPSP.EQ.1)GO TO 24
      IF(BRL.LT.CMIN)X(I)=A(I,17)
      IF(BR.LT.CMIN)X(I)=0
   24 IF(X(I).EQ.ZLB(I))INDEX(I)=1
      IF(X(I).EQ.ZUB(I))STOP(I)=1
      BR=BR-X(I)*C(I)
      BRL=BRL-X(I)*C(I)
      GO TO 21
   30 RETURN
      END
C
      SUBROUTINE MODVTU(N,B,X,BR,Z,Z1,C,E,H,P2,INS,NSO,VTD,
     *MRU,INDEX,STOP)
C *** VARIABLE THRESHOLD MODEL - UNBOUNDED; THE UPPER BOUND ON DEPTH
C *** AND THE SPCC STOPPING RULE ARE ELIMINATED.
      REAL V(1000),RISK(1000),C(N),E(N),H,P2(N),Z(N),Z1(N),BR,BRL
      INTEGER INDEX(N),Q,X(N),Y(1000),D,INS(N),NSO(N),STOP(N)
      INTEGER VTD(N),XX(1000),MRU(N),Q1,Q2,ZLB(1000)
      INTEGER*4 AY/'YES '/,AN/'NO  '/
      COMMON SN(1000,9),A(1000,17)
      CMIN=C(1)
C *** THE AVAILABLE BUDGET IS FIRST REDUCED BY INSURANCE AND NSO
C *** MINIMUMS.
      BRL=B
      DO 10 I=1,N
      IF(INS(I).EQ.1)GO TO 8
      IF(NSO(I).EQ.1)GO TO 8
      XX(I)=0
      GO TO 10
    8 XX(I)=MRU(I)
   10 BRL=BRL-XX(I)*C(I)
      DO 20 I=1,N
         INDEX(I)=0
         STOP(I)=0
         IF(INS(I).EQ.1)GO TO 14
         ZLB(I)=MAX1(1.,(Z(I)+0.9999))
         IF(Z(I).GT.120.)GO TO 12
         V(I)=(1-EXP(-Z(I)))/C(I)
         GO TO 13
   12    V(I)=1/C(I)
   13    RISK(I)=H*C(I)/(H*C(I)+P2(I)*E(I))
         Y(I)=NFX(Z(I),RISK(I))
         IF (C(I) .LT. CMIN) CMIN=C(I)
         D=MAX0(Y(I),XX(I),ZLB(I))
         Y(I)=D
         GO TO 15
   14    Y(I)=MRU(I)
```

```
   15    X(I)=0
         DO 16 J=1,9
   16    A(I,J)=SN(I,J)
         A(I,10)=INS(I)
         A(I,11)=V(I)
         A(I,12)=Y(I)-XX(I)
         A(I,13)=C(I)
         A(I,14)=NSO(I)
         A(I,15)=MRU(I)
         A(I,16)=VTD(I)
         A(I,17)=XX(I)
   20 CONTINUE
C *** THE CALL TO SORT IS ACTUALLY NOT NEEDED FOR SPCC DATA SINCE
C *** IT COMES SORTED ON THE TAPES THAT WAY.
C     CALL SORT(N)
      I=0
      BR=B
   21 IF(I.EQ.N)GO TO 30
      I=I+1
      Q1=A(I,12)
      Q2=BRL/C(I)
      Q=MIN0(Q1,Q2)
      X(I)=Q+A(I,17)
      NSO(I)=A(I,14)
      VTD(I)=A(I,16)
      IF(NSO(I).EQ.1)GO TO 22
      NSO(I)=AN
      GO TO 23
   22 NSO(I)=AY
   23 IF(BRL.LT.CMIN)X(I)=A(I,17)
      IF(BR.LT.CMIN)X(I)=0
      IF(X(I).EQ.ZLB(I))INDEX(I)=1
      BR=BR-X(I)*C(I)
      BRL=BRL-X(I)*C(I)
      GO TO 21
   30 RETURN
      END
C
      SUBROUTINE MODOPT(N,B,AMODEL,X,BR,Z,PCLT,C,E,RR,SR,INS,MRU,INDEX,
     *STOP,NN1,NNN,Z1)
C *** ROUTINE PERFORMS OPTIMAL ALLOCATION FOR A PROPOSED NEW MODEL
C *** (G-E AND MSRT) USING THE MARGINAL ANALYSIS METHOD.
C *** AMODEL=ENTRY POINT FOR A PROPOSED MODEL (STANDARIZED ARGUMENTS).
C *** RR=WORK VECTOR TO STORE MARGINAL ANALYSIS RATIOS.
C *** SR=LAST MAX RATIO; A SHADOW COST.
      INTEGER N,I,K,MK,STEP,X(N),STOP(N),XL(1000),INDEX(N)
      INTEGER INS(N),MRU(N),INDEXC(1000),NN,NN1,NNN
      REAL Z(N),C(N),E(N),B,PCLT(N),BR,MR,RR(N),SR,Z1(N),PCLT1(1000)
      SR=0.
      NN1=0
      BR=B
C *** INSURANCE ITEMS ARE BOUGHT FIRST.
      DO 10 I=1,N
      IF(INS(I).EQ.0)GO TO 10
```

```
      X(I)=MRU(I)
      BR=BR-X(I)*C(I)
   10 CONTINUE
C *** NSO ITEMS WOULD BE BOUGHT NEXT. HOWEVER,
C   * SINCE THERE WERE NO NSO'S IN THE DATA
C *** THE NSO STEP HAS BEEN ELIMINATED.
      DO 11 I=1,N
         IF(INS(I).EQ.1)GO TO 11
         X(I)=0
         PCLT1(I)=PCLT(I)+1.0
C *** THE NEXT INDICES ARE USED TO LATER TO IDENTIFY ITEMS WHICH WILL
C   * HAVE FORCED LOWER BOUNDS OR FOR WHICH THE BUDGET LEFT IS LESS
C *** THAN THEIR C(I) VALUES.
         INDEX(I)=0
         INDEXC(I)=0
C *** INITIALIZE STOP BEFORE OPTIMIZING ON SMA OR MSRT.(STOP=1 MEANS
C *** THAT THE LEVEL HAS HIT THE GRE OR MSRT BOUND).
         STOP(I)=0
         RR(I)=AMODEL(Z1(I),PCLT1(I),C(I),E(I),X(I)+1,STOP(I))
   11 CONTINUE
C *** DO UNTIL ALL THE BUDGET IS ALLOCATED.
   20 CONTINUE
      MK=0
      MR=-1.
      DO 30 K=1,N
          IF(INS(K).EQ.1)GO TO 30
          IF(STOP(K).EQ.1)GO TO 30
          IF(C(K).GT.BR)INDEXC(K)=1
          IF(INDEXC(K).EQ.1)GO TO 30
          IF(RR(K).LE.MR)GO TO 30
          MR=RR(K)
          MK=K
   30 CONTINUE
      IF(MK.EQ.0)GO TO 39
C *** ALLOCATE ONE MORE UNIT OF ITEM MK IF POSSIBLE.
      BR=BR-C(MK)
      X(MK)=X(MK)+1
      SR=MR
      RR(MK)=AMODEL(Z1(MK),PCLT1(MK),C(MK),E(MK),X(MK)+1,STOP(MK))
      GO TO 20
C *** THE FOLLOWING STEPS ARE USED TO SET 2 OR MORE ITEMS WHICH HAVE
C   * LEVELS BELOW THEIR PCLT DEMAND AND ABOVE ZERO TO THEIR  PCLT BOUND
C   * AND TO ZERO ALL THE OTHER LEVELS IN PREPARATION FOR A SECOND AND
C   * MORE ATTEMPTS TO OBTAIN A CONSTRAINED (BY SPCC'S LOWER BOUND)
C   * OPTIMAL SOLUTION. NN IS THE NUMBER OF ITEMS FORCED UP TO THEIR
C   * LOWER BOUNDS; NN1 IS THE ACTUAL NO. OF ITERATIONS DURING THE
C *** LOWER BOUND CONSTRAINED OPTIMIZATION STEPS.
   39 NN=0
      NN1=NN1+1
      IF(NN1.GE.NNN)GO TO 40
      DO 41 I=1,N
      XL(I)=Z(I)+0.9999
      IF(X(I).GE.XL(I))GO TO 41
      IF(X(I).EQ.0)GO TO 41
```

```
C *** A NORMAL APPROXIMATION IX NEEDED WHEN ZZ.GE.20. IT USES THE IMSL
C *** ROUTINE MDNOR TO COMPUTE THE CDF FOR A GIVEN DEVIATE VALUE.
   20 S=FLOAT(K)+0.5
      T1=(S-ZZ)/SQRT(ZZ)
      T2=(S-ZZ-1.0)/SQRT(ZZ)
      CALL MDNOR(T1,C1)
      CALL MDNOR(T2,C2)
      TWUS=(PCLT/2.)*(C1*(K-(K*(K+1)/ZZ))-C2*(ZZ-K)+
     *(ZZ-2.*K+K*(K+1)/ZZ))
   30 RETURN
      END
C
      REAL FUNCTION MODGRE(Z,PCLT,C,E,K,STOP)
C *** ROUTINE TO COMPUTE THE GROSS EFFECTIVENESS (GRE) AND
C   * THE MARGINAL ANALYSIS RATIO FOR THE GRE MODEL.
C *** THE DEMAND IS ASSUMED TO BE POISSON DISTRIBUTED.
      REAL Z,PCLT,C,E,P,CD,SMA,T1,T2,C1,C2,S,SK
      INTEGER K,STOP
      IF(Z.GE.20.)GO TO 10
      CALL CDFP(Z,K-1,P,CD)
C *** THE GRE MARGINAL ANALYSIS RATIO.
      MODGRE=(E/C)*(1.-CD)
      CALL CDFP(Z,K,P,CD)
      GRE=(Z*(1.-P) + (K-Z)*(1.-CD))/Z
      GO TO 11
C *** THE NORMAL APPROXIMATION FOR Z.GE.20.
   10 S=FLOAT(K)+0.5
      SK=FLOAT(K)
      T1=(S-Z)/SQRT(Z)
      T2=(S-Z-1.0)/SQRT(Z)
      CALL MDNOR(T1,C1)
      CALL MDNOR(T2,C2)
      MODGRE=(E/C)*(1.-C2)
      GRE=(SK/Z)*(1.-C1)+C2
C *** ARBITRARY STOPPING TO PREVENT WASTING BUDGET.
   11 IF(GRE.GT.0.9999)STOP=1
      RETURN
      END
C
      SUBROUTINE PRTOUT(MD,NAME,BR,MR,N,E,X,Z,C,PCLT,OV,TOV,NOBJ,INDEX,
     *STOP,NN1,NNN,Z1)
C *** ROUTINE TO COMPUTE AND PRINT OUT RESULTS OF EACH MODEL'S
C *** PERFORMANCE.
      INTEGER NOBJ,X(N),MD,STOP(N),INDEX(N),XL(1000),NN,NNN
      REAL Z(N),C(N),E(N),OV(NOBJ,N),TOV(NOBJ),PCLT(N),MR,BR,Z1(N)
      REAL*8 NAME(3)
      COMMON SN(1000,9),A(1000,17)
      DO 5 I=1,N
    5 XL(I)=Z(I)+0.9999
      WRITE(6,100)
  100 FORMAT('1','*******************************************************
     ********************************')
      WRITE(6,101) MD,NAME,BR,MR,NN1,NNN
  101 FORMAT('0',1X,'MODEL (',I1,') ',3A8,2X,'BUDGET LEFT: $',F10.2,
```

```
      NN=NN+1
   41 CONTINUE
      IF(NN.LE.1)GO TO 40
      DO 44 I=1,N
      IF(X(I).GT.XL(I))GO TO 44
      IF(X(I).EQ.0)GO TO 44
      X(I)=XL(I)
      INDEX(I)=1
   44 CONTINUE
      BR=B
      DO 46 I=1,N
      IF(INS(I).EQ.1)GO TO 45
      IF(INDEX(I).EQ.1)GO TO 45
      X(I)=0
   45 IF(C(I)*X(I).GT.BR)X(I)=0
   46 BR=BR-C(I)*X(I)
      DO 47 I=1,N
      STOP(I)=0
      INDEXC(I)=0
      RR(I)=AMODEL(Z1(I),PCLT1(I),C(I),E(I),X(I)+1,STOP(I))
   47 CONTINUE
      GO TO 12
   40 RETURN
      END
C
      REAL FUNCTION MODMST(ZZ,PCLT,C,E,K,STOP)
C *** ROUTINE TO COMPUTE THE MEAN SUPPLY RESPONSE TIME (MSTR) AND
C   * THE MARGINAL ANALYSIS RATIO FOR THE MSRT MODEL.
C *** THE DEMAND IS ASSUMED TO BE POISSON DISTRIBUTED.
      REAL ZZ,PCLT,C,E,MSRT,MSRTD
      INTEGER K,STOP
C *** THE MARGINAL ANALYSIS RATIO.
      MODMST=(E/C)*(TWUS(ZZ,PCLT,K-1)-TWUS(ZZ,PCLT,K))
      MSRT=TWUS(ZZ,PCLT,K)/ZZ
      MSRTD=91.*MSRT
C *** ARBITRARY STOPPING RULE TO PREVENT WASTING BUDGET ON ITEMS HAVING
C *** BEEN ALLOCATED DEPTHS RESULTING IN VERY LOW MSRT VALUES .
      IF(MSRTD.LT.0.001)STOP=1
      RETURN
      END
C
      REAL FUNCTION TWUS(ZZ,PCLT,K)
C *** ROUTINE TO CALCULATE THE EXPECTED TIME WEIGHTED UNITS SHORT WHEN
C *** THE DEPTH IS K UNITS.
      REAL ZZ,PCLT,P,C1,C2,T1,T2,ZR
      INTEGER K
      ZR = ZZ/PCLT
      IF(ZZ.GE.20.)GO TO 20
      CALL CDFP(ZZ,K,P,C)
      IF (C.LE.0.999999)GO TO 10
      TWUS=0.0
      GO TO 30
   10 TWUS=(1.-C)*(ZZ**2-2.*ZZ*K+K*(K+1))/(2.*ZR) + P*PCLT*(ZZ-K)/2.
      GO TO 30
```

```
     * //'  SHADOW COST: ',F12.8,11X,'ITERATIONS: ',I2,2X,
     *'(MAX ITERS: ',I2,' )')
      WRITE(6,102)
  102 FORMAT('0',5X,'NIIN',5X,'DEPTH',5X,'GR-EF',4X,'MSRT(DAYS)',
     *4X,'UNIT COST',2X,'PROB-VAR',3X,'LOBD?',2X,'UPBD?')
C *** CALL THE SUBROUTINE TO COMPUTE THE MSRT AND GRE VALUES FOR THE
C *** MODEL BEING EVALUATED.
      CALL OBJECT(X,N,Z1,C,PCLT,OV,TOV,NOBJ,E)
      WRITE(6,103)((SN(I,J),J=1,9),X(I),(OV(J,I),J=1,NOBJ),C(I),Z(I),
     *INDEX(I),STOP(I),I=1,N)
  103 FORMAT(3X,9A1,I7,1X,F10.4,F12.3,5X,F9.2,2X,F8.3,2X,I4,4X,I4)
      WRITE(6,104) (TOV(I),I=1,NOBJ)
  104 FORMAT('0',1X,'OVERALL PERFORMANCE:',F8.4,F12.3)
      WRITE(6,105)
  105 FORMAT('-','*****************************************************
     ******************************')
      RETURN
      END
C
      SUBROUTINE OBJECT(X,N,Z1,C,PCLT,OV,TOV,NOBJ,E)
C *** ROUTINE TO COMPUTE THE MSRT AND GRE VALUES FOR THE MODEL BEING
C --- EVALUATED.  THE PROTECTION INTERVAL IS T=PCLT + 1 QUARTERS SINCE
C --- THE FIRST REPLENISHMENT BUY IS ASSUMED TO OCCUR, ON THE AVERAGE,
C *** AT THE END OF THE FIRST QUARTER.
      INTEGER N,NOBJ,X(N),XI
      REAL Z1(N),C(N),OV(NOBJ,N),TOV(NOBJ),SLT,PCLT(N),E(N),MSRT
      REAL S,T1,T2,CD,P,MSRTC,C1,C2,SXI,PCLT1(1000)
      DO 5 I=1,NOBJ
      TOV(I)=0.
    5 CONTINUE
      SLT=0.
      DO 20 I=1,N
          XI=X(I)
          PCLT1(I)=PCLT(I)+1.0
          SLT = SLT + Z1(I)*E(I)
          OV(1,I)=0.
C *** THE NEXT EQUATION IS MSRT FOR X=0.
          MSRT=PCLT1(I)/2
          IF(XI.EQ.0)GO TO 17
          IF(Z1(I).GE.20.)GO TO 14
          CALL CDFP(Z1(I),XI,P,CD)
          IF(CD.GT.0.999999)GO TO 16
          SMA=(Z1(I)*(1.-P)+(XI-Z1(I))*(1.-CD))/Z1(I)
          GO TO 15
C *** THE NORMAL APPROXIMATION.
   14     S=FLOAT(XI)+0.5
          T1=(S-Z1(I))/SQRT(Z1(I))
          T2=(S-Z1(I)-1.0)/SQRT(Z1(I))
          CALL MDNOR(T1,C1)
          CALL MDNOR(T2,C2)
          SXI=FLOAT(XI)
          GRE=(SXI/Z1(I))*(1.-C1)+C2
   15     MSRTC=TWUS(Z1(I),PCLT1(I),XI)/Z1(I)
          MSRT=AMAX1(MSRTC,0.0)
```

```
            OV(1,I)=AMIN1(GRE,1.0)
            GO TO 17
   16       OV(1,I)=1.0
            MSRT=0.0
   17       OV(2,I) = 91.*MSRT
            TOV(1) = TOV(1) + OV(1,I)*Z1(I)*E(I)
            TOV(2) = TOV(2) + OV(2,I)*Z1(I)*E(I)
   20 CONTINUE
      TOV(1)=TOV(1)/SLT
      TOV(2)=TOV(2)/SLT
      RETURN
      END
      INTEGER FUNCTION NFX(ZZ,RISK)
C *** ROUTINE TO FIND MIN X SUCH THAT CDF(X-1).GE.(1-RISK)
      REAL ZZ,R,RISK,TT,S2
      INTEGER NX,NB
      R=1.-RISK
      NX=0
C *** DO WHILE(CDF(NX).LT.R)
      IF(ZZ.GT.1.)GO TO 11
C *** THE POISSON DISTRIBUTION IS CALLED.
   10 CALL CDFP(ZZ,NX,P,C)
      IF(C.GE.R)GO TO 20
      NX=NX+1
      GO TO 10
   11 S2=2.03*ZZ**.701
      IF(ZZ.GE.20)GO TO 21
C *** THE NEGATIVE BINOMIAL DISTRIBUTION IS CALLED.
   12 CALL CDFB(ZZ,NX,S2,C,NB)
      IF(NB.EQ.1)GO TO 21
      IF(C.GE.R)GO TO 20
      NX=NX+1
      GO TO 12
   20 NFX=NX
      RETURN
C *** THE NORMAL DISTRIBUTION IS CALLED.
   21 CALL CDFN(R,TT)
      NFX=ZZ+TT*S2+0.9999
      RETURN
      END
C
      SUBROUTINE CDFP(ZZ,K,P,C)
C *** ROUTINE TO CALCULATE POISSON MASS AND CUMULATIVE DISTRIBUTION
C *** FUNCTIONS.
      REAL*8 ZZZ,PP,CC
      REAL ZZ,P,C
      INTEGER K,I
      ZZZ=ZZ
      PP=DEXP(-ZZZ)
      CC=PP
      IF(K.EQ.0)GO TO 11
      DO 10 I=1,K
      PP=PP*ZZZ/DFLOAT(I)
      CC=CC+PP
```

```
   10 CONTINUE
   11 P=PP
      C=CC
      RETURN
      END
C
      SUBROUTINE CDFB(ZZ,K,S2,C,NB)
C *** ROUTINE TO CALCULATE THE NEGATIVE BINOMIAL MASS AND CUMULATIVE
C *** DISTRIBUTION FUNCTIONS.
      REAL ZZ,C,S2
      REAL*8 ZZZ,PP,CC,BR,R,BK,S22,B,BQ
      INTEGER K,I,NB
      NB=0
      ZZZ=ZZ
      S22=S2**2
      BR=ZZZ/S22
      BQ=S22/ZZZ
      IF(BQ.LE.1.0)GO TO 8
      R=1.0-BR
      BK=(ZZZ**2)/(S22-ZZZ)
      IF(BK*DLOG(BQ).GT.9.0)GO TO 8
      PP=BR**BK
      CC=PP
      IF(K.EQ.0) GO TO 11
      GO TO 9
    8 NB=1
      RETURN
    9 DO 10 I=1,K
      B=DFLOAT(I-1)
      PP=PP*R*(B+BK)/DFLOAT(I)
      CC=CC+PP
   10 CONTINUE
   11 C=CC
      RETURN
      END
C
      SUBROUTINE CDFN(R,TT)
C *** ROUTINE TO CALCULATE THE NORMAL DEVIATE TT FOR A GIVEN VALUE OF R.
C   * THIS ROUTINE USES THE IMSL ROUTINE MDNRIS WHICH IS AVAILABLE ON
C *** THE NPS IBM 3033.
      INTEGER IER
      REAL R,TT
      CALL MDNRIS(R,TT,IER)
      RETURN
      END
C
      SUBROUTINE SORT(N)
      DIMENSION B(17)
      COMMON SN(1000,9),A(1000,17)
      M=N-1
    9 FLAG=0
      DO 10 I=1,M
      J=I+1
      IF(A(J,10).GT.A(I,10))GO TO 1
```

```
      GO TO 10
    1 DO 2 K=1,17
      B(K)=A(J,K)
      A(J,K)=A(I,K)
    2 A(I,K)=B(K)
      FLAG=1
   10 CONTINUE
      IF(FLAG.EQ.1)GO TO 9
   11 FLAG=0
      DO 15 I=1,M
      IF(A(I,10).EQ.1)GO TO 15
      J=I+1
      IF(A(J,11).GT.A(I,11))GO TO 12
      GO TO 15
   12 DO 13 K=1,17
      B(K)=A(J,K)
      A(J,K)=A(I,K)
   13 A(I,K)=B(K)
      FLAG=1
   15 CONTINUE
      IF(FLAG.EQ.1)GO TO 11
      RETURN
      END
```

A.2

```
      ****************************************************************
C *** PROGRAM TO TEST PROPOSED WHOLESALE PROVISIONING MODELS        ***
C *** USING ASO PROVISIONING PACKAGES.                             ***
C ********************************************************************
C *** MAIN PROGRAM:
      REAL PCLT(500),R,RR(500),TPOP(500),CPOP(500),C(500)
      REAL LAM,RISK(500),Z(500),FJPOP(500),B022(500),B022A(500)
      REAL B022B(500) F009(500),E(500),PCC,EI(29),AZ(500)
      REAL MODMST,MODGRE,OV(2,500),TOV(2),MR,AS(500),S(500)
      REAL MC,RMC,RWK,F001(500),F003(500),PROG(500),PLT(500)
      REAL PRGM/'N   '/,BOUND(2)
      REAL*8 B,BR
      REAL*8 NAME1(3)/'STRAIGHT',' LINE',' '/
      REAL*8 NAME2(3)/'D52 DEPT','H BY NPS',' '/
      REAL*8 NAME3(3)/'CONTRACT','OR D52 D','EPTH'/
      REAL*8 NAME4(3)/'MAXIMIZE',' GROSS E','FFECT. '/
      REAL*8 NAME6(3)/'MINIMIZE',' MSRT',' '/
      INTEGER N,Y(500),I,INS(500),DEPTH(500),CDEPTH(500),DEMAND(500)
      INTEGER MRU(500),NOBJ,STOP(500),X(500),XSL(500),INDEX(500)
      INTEGER INSQ(500),YY(500),NNN,NN1,BUDMET
      COMMON SN(500,9)
      EXTERNAL MODMST,MODGRE
C *** THE NEXT TWO PARAMETERS MUST BE SPECIFIED WHENEVER A NEW COG IS
C   * INTRODUCED; NRPR=0 MEANS A CONSUMABLE, NRPR=1 MEANS A REPAIRABLE.
C   * N=NO. OF ITEMS IN THE COG; THIS NUMBER IS PROVIDED BY THE OUTPUT
C   * OF THE PROGRAM WHICH WAS USED TO STRIP INFORMATION FROM THE ASO
C   * TAPE (SEE CHAPTER 3) AND ESTABLISH THE DATA SET OF INPUT DATA FOR
C *** THIS PROGRAM. FOR EXAMPLE, THE F/A-18 1R COG CONTAINED 470 ITEMS
       N=470
       NRPR=0
C *** THE NEXT PARAMETER CONTROLS WHETHER THE OPTIMIZATION PROCESS
C   * ALLOWS THE ICP LOWER BOUND CONSTRAINT (MEAN DEMAND DURING PROCURE
C   * MENT LEADTIME).IF NNN=1 THEN THE LOWER BOUND IS IGNORED. IF
C   * NNN IS LARGE THE LOWER BOUNDING IS ALLOWED FOR AS MANY ITERATIONS
C   * AS NNN. NNN IS THEN USED TO PREVENT WASTING TIME ON AN INFEASIBLE
C   * PROBLEM WHEN THE BUDGET IS TOO SMALL.
C *** NN1 IS THE ITERATION COUNTER.
      NNN=10
      NN1=1
C *** NOBJ SPECIFIES THE NUMBER OF EVALUATION MEASURES TO BE USED FOR
C   * COMPARING MODELS. THIS WAS SET AT TWO SINCE THE MEAN SUPPLY
C   * RESPONSE TIME (MSRT) AND GROSS EFFECTIVENESS (G-E) WERE THE
C *** ONLY ONES USED.
      NOBJ=2
C *** THE DATA FOR EACH TEST PACKAGE IS READ FROM THE INPUT DATA SET.
C   * THE NOTATION CORRESPONDS TO THE ASO NOTATION USED IN D52 AND
C   * THE FORMULAS PRESENTED IN CHAPTER 3 FOR ESTIMATING DEMAND. PCC
C   * IS THE PROVISIONING CONTROL CODE USED BY ASO TO IDENTIFY EACH
C   * PACKAGE (SEE CHAPTER 4). SN DENOTES THE STOCK NUMBER, PROG=N
C   * MEANS DEMAND IS NOT RELATED TO FLYING HOURS (SEE CHAPTER 3).
```

```
C   * THE DEPTH, CDEPTH, AND DEMAND VALUES WERE DATA ELEMENTS FROM THE
C   * RESULTS OF ASO'S RUNNING OF THEIR D52 PROGRAM AND WERE USED TO
C   * CHECK THE D52 MODEL PROGRAM (MODASO) FOR VALIDITY AS A
C   * REASONABLE REPRESENTATION OF THE ACTUAL ONE USED BY ASO.
C   * THE DEPTH VALUE WAS ALSO USED TO GENERATE THE BUDGET DEVELOPED
C   * THE F/A-18 CONTRACTOR. THE PERFORMANCES OF THE VARIOUS MODELS
C   * FOR THAT BUDGET WERE INCLUDED IN THE ANALYSES IN THIS REPORT.
C   * BUDMET (BUDGET METHOD) IS 1 IF THE STRAIGHT LINE METHOD WAS USED
C *** AND 2 IF THE CONTRACTOR'S BUDGET WAS USED.
      BUDMET=0
      READ(1,800)PCC,EI
  800 FORMAT(A3,29A1)
      READ(1,801)COG,LAM,MC,RMC,RWK
  801 FORMAT(A2,F15.7,3F4.0)
      DO 10 I=1,N
      E(I)=1.0
      RISK(I)=0.0
      INDEX(I)=0
      STOP(I)=0
   10 CONTINUE
      READ(1,802)((SN(I,J),J=1,9),C(I),PROG(I),TPOP(I),CPOP(I),FJPOP(I),
     *B022(I),B022A(I),B022B(I),F001(I),F003(I),F009(I),
     *PCLT(I),MRU(I),INS(I),INSQ(I),DEPTH(I),CDEPTH(I),DEMAND(I),I=1,N)
  802 FORMAT(9A1,F10.2,A1,1X,3F8.2,3F9.3,F7.3,2F4.2,F5.2,2X,
     *3I4,I6,I8,I7)
      IF(NRPR.EQ.1)GO TO 21
C *** DETERMINE THE MEAN DEMAND AND STD DEV. OVER PCLT FOR
C   * CONSUMABLES(1R); DO ALSO FOR PCLT +1. NOTE THAT FOR THE EVALUATION
C   * OF THE MODELS THAT ASO'S INTERVAL OF PROTECTION IS PCLT SINCE THE
C   * FIRST REPLENISHMENT BUY IS EXPECTED TO BE MADE SHORTLY AFTER
C *** THE MATERIAL SUPPORT DATE (SEE CHAPTER 2).
      DO 20 I=1,N
         PLT(I)=AMAX1(4.,PCLT(I))
         IF(PROG(I).EQ.PRGM)GO TO 15
         A1=MC*PLT(I)*TPOP(I)*B022(I)/6
         A2=RMC*PLT(I)*FJPOP(I)*B022A(I)/6
         A3=RWK*PLT(I)*CPOP(I)*B022A(I)/6
         GO TO 16
C *** IF NOT PROGRAM RELATED, A1,A2,AND A3 CHANGE.
   15    A1=MC*PLT(I)*TPOP(I)*F001(I)/6
         A2=RMC*PLT(I)*FJPOP(I)*F003(I)/6
         A3=RWK*PLT(I)*CPOP(I)*F003(I)/6
   16    Z(I)=A1+A2+A3
         AZ(I)=Z(I)*(PLT(I)+1.)/PLT(I)
         S(I)=(2.1735*Z(I)**0.717)/((PLT(I)*3)**0.217)
   20 CONTINUE
      GO TO 30
C *** DETERMINE THE MEAN DEMAND AND STD DEV. OVER PCLT FOR
C *** REPAIRABLES(2R); DO ALSO FOR PCLT +1.
   21 DO 26 I=1,N
         PLT(I)=AMAX1(4.,PCLT(I))
         IF(PROG(I).EQ.PRGM)GO TO 24
         IF(B022(I).GE.B022B(I))GO TO 23
         IF(B022(I).EQ.0.0)GO TO 22
```

```
      B022B(I)=B022(I)
      GO TO 23
   22 B022(I)=B022B(I)
   23 AR1=MC*PLT(I)*TPOP(I)*B022(I)/6
      GO TO 25
C *** IF NOT PROGRAM RELATED, AR1 CHANGES.
   24 AR1=MC*PLT(I)*TPOP(I)*F001(I)/6
   25 AR2=RMC*PLT(I)*TPOP(I)*B022B(I)*F009(I)/6
      Z(I)=AR1-AR2
      AZ(I)=Z(I)*(PLT(I)+1.)/PLT(I)
      S(I)=(2.1735*Z(I)**0.717)/((PLT(I)*3)**0.217)
   26 CONTINUE
C *** PREPARE A TABLE SHOWING PACKAGE AND ITEM PARAMETER VALUES AND
C *** THE DEPTHS USED TO GENERATE THE BUDGET CONSTRAINT.
   30 WRITE(6,900)
  900 FORMAT('1',///,' ***********************************************
     *******************************')
      WRITE(6,901)EI,PCC,COG,N
  901 FORMAT('0','***  END ITEM: ',29A1,3X,'PCC: ',A3,3X,'COG: ',
     *A2,3X,'N: ',I4,2X,'***')
      WRITE(6,902)
  902 FORMAT('0','*****************************************************
     *************************')
      IF(BUDMET.EQ.2)GO TO 32
C *** STRAIGHT LINE BUDGET MODEL
      CALL STRLIN(N,B,C,Z,AZ,PLT,INS,INSQ,X,INDEX)
C *** STRAIGHT LINE METHOD PERFORMANCE
      CALL PRTOUT(1,NAME1,0.0,0.0,N,E,X,Z,C,PLT,INS,OV,TOV,NOBJ,INDEX,
     *STOP,NN1,NNN)
C *** BECAUSE THE STRAIGHT LINE METHOD CAN GIVE AN VERY AUSTERE BUDGET,
C   * THE MARGINAL ANALYSIS PROCEDURE OF ROUTINE MODOPT CAN GIVE A WORSE
C   * SOLUTION THAN THE STRAIGHT LINE. THEREFORE A BAD MODOPT SOLUTON
C   * NEEDS TO BE IDENTIFIED. THE FOLLOWING STEPS SET THE BASIS FOR
C *** DETERMINING THAT.
      BOUND(1)=TOV(1)
      BOUND(2)=TOV(2)
      DO 31 I=1,N
   31 XSL(I)=X(I)
      GO TO 33
C *** D52/CONTRACTOR'S BUDGET MODEL
   32 CALL COND52(N,B,C,Z,AZ,PLT,INS,INSQ,DEPTH,DEMAND,X,INDEX)
C *** CONTRACTOR'S MODEL PERFORMANCE
      CALL PRTOUT(3,NAME3,0.0,0.0,N,E,X,Z,C,PLT,INS,OV,TOV,NOBJ,INDEX,
     *STOP,NN1,NNN)
      GO TO 34
   33 CALL MODD52(N,Z,S,B,BR,C,X,INS,INSQ,MRU,INDEX)
      CALL PRTOUT(2,NAME2,BR,0.0,N,E,X,Z,C,PLT,INS,OV,TOV,NOBJ,INDEX,
     *STOP,NN1,NNN)
   34 NOPT=1
C *** MODEL TO MAXIMIZE GROSS EFFECTIVENESS
      CALL MODOPT(N,B,MODGRE,X,BR,Z,PLT,C,E,RR,MR,INS,INSQ,INDEX,STOP,
     *BOUND,XSL,KSL,NN1,NNN,NOPT)
      CALL PRTOUT(4,NAME4,BR,MR,N,E,X,Z,C,PLT,INS,OV,TOV,NOBJ,INDEX,
     *STOP,NN1,NNN)
```

```
C *** MODEL TO MINIMIZE MEAN SUPPLY RESPONSE TIME
      NOPT=2
      CALL MODOPT(N,B,MODMST,X,BR,Z,PLT,C,E,RR,MR,INS,INSQ,INDEX,STOP,
     *BOUND,XSL,NN1,NNN,NOPT)
      CALL PRTOUT(5,NAME5,BR,MR,N,E,X,Z,C,PLT,INS,OV,TOV,NOBJ,INDEX,
     *STOP,NN1,NNN)
      STOP
      END
C
      SUBROUTINE STRLIN(N,B,C,Z,AZ,PLT,INS,INSQ,X,INDEX)
C *** THE BUDGET IS COMPUTED BY THE STRAIGHT LINE METHOD.
      INTEGER X(N),INS(N),INSQ(N),INDEX(N)
      REAL Z(N),AZ(N),PLT(N),C(N)
      REAL*8 B,BB
      COMMON SN(500,9)
      B=0.0
      BB=0.0
      WRITE(6,20)
   20 FORMAT('-',12X,'BUDGET COMPUTED BY THE STRAIGHT LINE METHOD')
      WRITE(6,21)
   21 FORMAT('-','   NIIN      DEPTH   PROB-VAR     PCLT',
     * '     UNIT COST          BUDGET     INS? ')
      DO 10 I=1,N
      X(I)=INSQ(I)
      IF(INS(I).EQ.1)GO TO 9
      X(I)=AZ(I)+0.5
      LB=AZ(I)+0.5
      IF(X(I).EQ.LB)INDEX(I)=1
    9 B=B+C(I)*X(I)
      IF(INS(I).EQ.1)GO TO 10
      BB=BB+C(I)*X(I)
   10 WRITE(6,22)(SN(I,J),J=1,9),X(I),Z(I),PLT(I),C(I),B,INS(I)
   22 FORMAT(' ',9A1,3X,I4,4X,F8.3,3X,F7.2,3X,F10.2,3X,F12.2,3X,I4)
      WRITE(6,23)BB
   23 FORMAT('-',10X,'TOTAL BUDGET FOR NON-INSURANCE ITEMS = $',F12.2)
      RETURN
      END
C
      SUBROUTINE COND52(N,B,C,Z,AZ,PLT,INS,INSQ,DEPTH,DEMAND,X,INDEX)
C *** THE BUDGET IS COMPUTED USING THE CONTRACTOR' DEPTHS.
      INTEGER X(N),INS(N),INSQ(N),DEPTH(N),DEMAND(N),INDEX(N)
      REAL C(N),Z(N),AZ(N),PLT(N)
      REAL*8 B,BB
      COMMON SN(500,9)
      B=0.0
      BB=0.0
      WRITE(6,20)
   20 FORMAT('-',12X,'BUDGET COMPUTED FROM D52 RUN BY CONTRACTOR')
      WRITE(6,21)
   21 FORMAT('-','   NIIN      DEPTH   PROB-VAR     PCLT',
     * '     UNIT COST          BUDGET     INS?     MDEMAND')
      DO 10 I=1,N
      X(I)=INSQ(I)
      IF(INS(I).EQ.1)GO TO 9
```

```
      X(I)=DEPTH(I)
      INDEX(I)=1
    9 B=B+C(I)*X(I)
      IF(INS(I).EQ.1)GO TO 10
      BB=BB+C(I)*X(I)
   10 WRITE(6,22)(SN(I,J),J=1,9),X(I),Z(I),PLT(I),C(I),B,INS(I),
     *DEMAND(I)
   22 FORMAT(' ',9A1,3X,I4,4X,F8.3,3X,F7.2,5X,F9.2,3X,F12.2,3X,I4,5X,I4)
      WRITE(6,23)BB
   23 FORMAT('-',10X,'TOTAL BUDGET FOR NON-INSURANCE ITEMS = $',F12.2)
      RETURN
      END
C
      SUBROUTINE MODD52(N,Z,S,B,BR,C,X,INS,INSQ,MRU,INDEX)
C *** THIS IS A REPLICATION OF THE ROUTINE DESCRIBED IN D52 FOR
C   * THE PROCEDURE USED BY ASO TO DETERMINE DEPTHS FOR LARGE
C *** PROVISIONING PACKAGES. A BISECTION SEARCH IS USED.
      INTEGER X(N),MRU(N),INS(N),INSQ(N),LB,INDEX(N)
      REAL Z(N),S(N),RISK4,C(N)
      REAL*8 R1(500),R2(500),RISK,RATIO,CMIN
      REAL*8 TMIN,TMAX,TLAST,THETA
      REAL*8 B,BR,B1,BT,B2,BL,BU,DEN,DEN1,RSK(500)
      DATA EPS/0.000001/
      B1=B
      M=0
      DIFF=0.0
      BL=0.05
      BU=0.5
      DEN1=5000000.
C *** INSURANCE ITEMS ARE BOUGHT FIRST.
      DO 5 I=1,N
      INDEX(I)=0
      IF(INS(I).EQ.0)GO TO 5
      X(I)=INSQ(I)
      B1=B1-X(I)*C(I)
    5 CONTINUE
      B2=B-B1
C *** NON-INSURANCE ITEMS ARE BOUGHT NEXT.
C   * COMPUTE ITEM DEPTH GIVEN THE BUDGET BY USING BISECTION SEARCH TO
C *** DETERMINE THE ASO LAGRANGE MULTIPLIER LAMBDA OF D52.
      TMIN=9999999.
      CMIN=5000000.
      DO 10 I=1,N
      IF(INS(I).EQ.1)GO TO 10
      IF(C(I).LT.CMIN)CMIN=C(I)
      DEN=19.0*C(I)
      IF(DEN.GE.DEN1)GO TO 9
      R1(I)=Z(I)/(19.0*C(I))
      IF(R1(I).LT.TMIN)TMIN=R1(I)
      GO TO 10
    9 TMIN=0.0
   10 CONTINUE
C *** COMPUTE INITIAL DEPTHS USING TMIN ; THE DEPTH WILL BE THE MAXIMUM
C *** ALLOWABLE IN D52.
```

```
      BT=0.0
      DO 20 I=1,N
      IF(INS(I).EQ.1)GO TO 19
      IF(Z(I).EQ.0.0)GO TO 19
      RATIO=TMIN*C(I)/(TMIN*C(I)+Z(I))
      RISK=DMIN1(BU,DMAX1(RATIO,BL))
      RISK4=RISK
      RSK(I)=RISK
      X(I)=NFX(Z(I),S(I),RISK4)
      GO TO 20
   19 X(I)=0
      RISK=0.0
      RSK(I)=0.0
   20 BT=BT+C(I)*X(I)
      IF(BT.LE.B1)GO TO 99
C *** SINCE MAX DEPTH COMSUMES MORE THAN THE AVAILABLE BUDGET THE
C *** OTHER END OF THE SPECTRUM IS TRIED. THAT END WILL ALWAYS BE
C *** FEASIBLE WHEN THE STRAIGHT LINE METHOD GENERATES THE BUDGET.
      TMAX=0.0
      DO 30 I=1,N
      IF(INS(I).EQ.1)GO TO 30
      R2(I)=Z(I)/C(I)
      IF(R2(I).GT.TMAX)TMAX=R2(I)
   30 CONTINUE
      BT=0.0
      DO 40 I=1,N
      IF(INS(I).EQ.1)GO TO 39
      IF(Z(I).EQ.0.0)GO TO 39
      RATIO=TMAX*C(I)/(TMAX*C(I)+Z(I))
      RISK=DMIN1(BU,DMAX1(RATIO,BL))
      RISK4=RISK
      RSK(I)=RISK
      X(I)=NFX(Z(I),S(I),RISK4)
      GO TO 40
   39 X(I)=0
      RISK=0.0
   40 BT=BT+C(I)*X(I)
      IF(DABS(BT-B1).LE.0.01*B1)GO TO 99
C *** THE SEARCH NOW TURNS TOWARD THE CENTER OF THE RANGE AND
C *** ITERATES UNTIL A STOPPING POINT IS REACHED; USUALLY DUE
C *** A CHANGE IN THETA BECOMING VERY SMALL.
      TLAST=TMAX
   45 THETA=(TMIN+TMAX)/2
      M=M+1
      BT=0.0
      DO 50 I=1,N
      IF(INS(I).EQ.1)GO TO 49
      IF(Z(I).EQ.0.0)GO TO 49
      RATIO=THETA*C(I)/(THETA*C(I)+Z(I))
      RISK=DMIN1(BU,DMAX1(RATIO,BL))
      RISK4=RISK
      RSK(I)=RISK
      X(I)=NFX(Z(I),S(I),RISK4)
      GO TO 50
```

```
   49 X(I)=0
      RISK=0.0
      RSK(I)=0.0
   50 BT=BT+C(I)*X(I)
      IF(DABS(BT-B1).LE.0.01*B1.AND.BT.GT.B1)GO TO 99
      IF(BT.GT.B1)GO TO 51
      IF((BT+CMIN).GT.B1)GO TO 99
      IF(DABS(THETA-TLAST).LT.EPS)GO TO 99
      TMAX=THETA
      GO TO 52
   51 TMIN=THETA
   52 TLAST=THETA
      GO TO 45
   99 BR=B1-BT
      DO 100 I=1,N
      LB=Z(I)+0.5
      IF(X(I).EQ.LB)INDEX(I)=1
      IF(RSK(I).EQ.BL)INDEX(I)=2
      IF(INS(I).EQ.1)INDEX(I)=9
      IF(INS(I).EQ.1)X(I)=INSQ(I)
  100 CONTINUE
      RETURN
      END
C
C
      SUBROUTINE MODOPT(N,B,AMODEL,X,BR,Z,PLT,C,E,RR,SR,INS,INSQ,INDEX,
     *STOP,BOUND,XSL,NN1,NNN,NOPT)
C *** ROUTINE PERFORMS OPTIMAL ALLOCATION FOR A PROPOSED NEW MODEL
C *** (G-E AND MSRT) USING THE MARGINAL ANALYSIS METHOD.
C *** AMODEL=ENTRY POINT FOR A PROPOSED MODEL (STANDARIZED ARGUMENTS).
C *** RR=WORK VECTOR TO STORE MARGINAL ANALYSIS RATIOS.
C *** SR=LAST MAX RATIO; A SHADOW COST.
      INTEGER I,K,MK,STEP,X(N),STOP(N),XL(500),INDEX(N),FREEZE(500)
      INTEGER INS(N),INSQ(N),INDEXC(500),NN,NN1,NNN,XSL(N),KSL
      REAL Z(N),E(N),PLT(N),MR,RR(N),SR,BOUND(2),TRY
      REAL MODGRE,MODMST,TOV(2),OV(2,500),C(N)
      REAL*8 B,BR
      SR=0.
C *** INITIALIZE
      BR=B
C *** INSURANCE ITEMS ARE BOUGHT FIRST.
      DO 10 I=1,N
      IF(INS(I).EQ.0)GO TO 10
      X(I)=INSQ(I)
      BR=BR-X(I)*C(I)
   10 CONTINUE
C *** NON-INSURANCE ITEMS ARE BOUGHT NEXT. SINCE NO NSO'S WERE IN DATA
C *** THE NSO DETAILS WERE NOT CONSIDERED FURTHER.
      DO 11 I=1,N
         IF(INS(I).EQ.1)GO TO 11
         X(I)=0
C *** THE NEXT INDICES ARE USED TO IDENTIFY ITEMS WHICH MAY HAVE
C   * FORCED LOWER BOUNDS OR FOR WHICH THE BUDGET LEFT IS LESS
C *** THAN THEIR C(I) VALUES.
```

```
          INDEX(I)=0
          INDEXC(I)=0
C *** INITIALIZE STOP BEFORE OPTIMIZING ON SMA OR MSRT.(STOP=1 MEANS
C *** THAT THE LEVEL HAS HIT THE GRE OR MSRT BOUND).
          STOP(I)=0
          RR(I)=AMODEL(Z(I),PLT(I),C(I),E(I),X(I)+1,STOP(I))
   11 CONTINUE
      NN1=0
   12 STEP=0
C *** DO UNTIL ALL BUDGET USED
   20 CONTINUE
      STEP=STEP+1
      MK=0
      MR=-1.
      DO 30 K=1,N
          IF(INS(K).EQ.1)GO TO 30
          IF(STOP(K).EQ.1)GO TO 30
          IF(C(K).GT.BR)INDEXC(K)=1
          IF(INDEXC(K).EQ.1)GO TO 30
          IF(RR(K).LE.MR)GO TO 30
          MR=RR(K)
          MK=K
   30 CONTINUE
      IF(MK .EQ. 0) GO TO 40
C *** ALLOCATE ONE MORE UNIT OF ITEM MK IF POSSIBLE.
      BR=BR-C(MK)
      X(MK)=X(MK)+1
      SR=MR
      RR(MK)=AMODEL(Z(MK),PLT(MK),C(MK),E(MK),X(MK)+1,STOP(MK))
      GO TO 20
C *** THE FOLLOWING STEPS ARE USED TO SET 2 OR MORE ITEMS WHICH HAVE
C   * LEVELS BELOW THEIR PCLT DEMAND AND ABOVE ZERO TO THEIR  PCLT BOUN
C   * AND TO ZERO ALL THE OTHER LEVELS IN PREPARATION FOR A SECOND AND
C   * MORE ATTEMPTS TO OBTAIN A CONSTRAINED (BY SPCC'S LOWER BOUND)
C   * OPTIMAL SOLUTION. NN IS THE NUMBER OF ITEMS FORCED UP TO THEIR
C   * LOWER BOUNDS; NN1 IS THE ACTUAL NO. OF ITERATIONS DURING THE
C *** LOWER BOUND CONSTRAINED OPTIMIZATION STEPS.
   40 NN=0
      NN1=NN1+1
      IF(NN1.GE.NNN)GO TO 55
      DO 41 I=1,N
      XL(I)=Z(I)+0.5
      IF(X(I).EQ.XL(I))INDEX(I)=1
      IF(X(I).GE.XL(I))GO TO 41
      IF(X(I).EQ.0)GO TO 41
      NN=NN+1
   41 CONTINUE
      IF(NN.LE.1)GO TO 48
      DO 44 I=1,N
      IF(X(I).GE.XL(I))GO TO 44
      IF(X(I).EQ.0)GO TO 44
      X(I)=XL(I)
      INDEX(I)=1
   44 CONTINUE
```

```
      BR=B
      DO 46 I=1,N
      IF(INS(I).EQ.1)GO TO 45
      IF(INDEX(I).EQ.1)GO TO 45
      X(I)=0
   45 IF(C(I)*X(I).GT.BR)X(I)=0
   46 BR=BR-C(I)*X(I)
      DO 47 I=1,N
      STOP(I)=0
      INDEXC(I)=0
      RR(I)=AMODEL(Z(I),PLT(I),C(I),E(I),X(I)+1,STOP(I))
   47 CONTINUE
      GO TO 12
C *** COMPARE RESULTS AGAINST THE STRAIGHT LINE METHOD TO DETERMINE IF
C   * MARGINAL ANALYSIS IS GIVING NON-OPTIMAL RESULTS
C *** (MAY BE NEEDED FOR SMALL PACKAGES OR FOR VERY LIMITED BUDGETS).
   48 CALL OBJECT(X,N,Z,C,PLT,INS,OV,TOV,NOBJ,E,ASOSMA)
      IF(TOV(2).LE.BOUND(2))GO TO 55
      IF(NOPT.EQ.2)GO TO 52
      IF(TOV(1).GE.BOUND(1))GO TO 55
C *** SET SOLUTION EQUAL TO STRAIGHT LINE QUANTITIES SINCE THE
C *** STRAIGHT LINE SOLUTION IS OPTIMAL FOR THE NEW MODEL ALSO.
   52 DO 53 I=1,N
   53 X(I)=XSL(I)
      BR=0.0
   55 RETURN
      END
C
      REAL FUNCTION MODMST(ZZ,PLT,C,E,K,STOP)
C *** ROUTINE TO COMPUTE THE MEAN SUPPLY RESPONSE TIME (MSTR) AND
C   * THE MARGINAL ANALYSIS RATIO FOR THE MSRT MODEL.
C *** THE DEMAND IS ASSUMED TO BE POISSON DISTRIBUTED.
      REAL ZZ,PLT,C,E,MSRT,MSRTD
      INTEGER K,STOP
C *** THE MARGINAL ANALYSIS RATIO.
      MODMST=(E/C)*(TWUS(ZZ,PLT,K-1)-TWUS(ZZ,PLT,K))
      MSRT=TWUS(ZZ,PLT,K)/ZZ
      MSRTD=91.*MSRT
C *** ARBITRARY STOPPING RULE TO PREVENT WASTING BUDGET ON ITEMS HAVING
C *** BEEN ALLOCATED DEPTHS RESULTING IN VERY LOW MSRT VALUES .
      IF(MSRTD.LT.0.001)STOP=1
      RETURN
      END
C
      REAL FUNCTION TWUS(ZZ,PLT,K)
C *** ROUTINE TO CALCULATE THE EXPECTED TIME WEIGHTED UNITS SHORT WHEN
C *** THE DEPTH IS K UNITS.
      REAL ZZ,PLT,P,C1,C2,T1,T2,ZR
      INTEGER K
      ZR = ZZ/PLT
      IF(ZZ.GE.20.)GO TO 20
      CALL CDFP(ZZ,K,P,C)
      IF (C.LE.0.999999)GO TO 10
      TWUS=0.0
```

```
      GO TO 30
   10 TWUS=(1.-C)*(ZZ**2-2.*ZZ*K+K*(K+1))/(2.*ZR) + P*PLT*(ZZ-K)/2.
      GO TO 30
C *** A NORMAL APPROXIMATION IX NEEDED WHEN ZZ.GE.20. IT USES THE IMSL
C *** ROUTINE MDNOR TO COMPUTE THE CDF FOR A GIVEN DEVIATE VALUE.
   20 S=FLOAT(K)+0.5
      T1=(S-ZZ)/SQRT(ZZ)
      T2=(S-ZZ-1.0)/SQRT(ZZ)
      CALL MDNOR(T1,C1)
      CALL MDNOR(T2,C2)
      TWUS=(PLT/2.)*(C1*(K-(K*(K+1)/ZZ))-C2*(ZZ-K)+
     *(ZZ-2.*K+K*(K+1)/ZZ))
   30 RETURN
      END
C
      REAL FUNCTION MODGRE(Z,PLT,C,E,K,STOP)
C *** ROUTINE TO COMPUTE THE GROSS EFFECTIVENESS (GRE) AND
C   * THE MARGINAL ANALYSIS RATIO FOR THE GRE MODEL.
C *** THE DEMAND IS ASSUMED TO BE POISSON DISTRIBUTED.
      REAL Z,PLT,C,E,P,CD,SMA,T1,T2,C1,C2,S,SK
      INTEGER K,STOP
      IF(Z.GE.20.)GO TO 10
      CALL CDFP(Z,K-1,P,CD)
C *** THE GRE MARGINAL ANALYSIS RATIO.
      MODGRE=(E/C)*(1.-CD)
      CALL CDFP(Z,K,P,CD)
      GRE=(Z*(1.-P) + (K-Z)*(1.-CD))/Z
      GO TO 11
C *** THE NORMAL APPROXIMATION FOR Z.GE.20.
   10 S=FLOAT(K)+0.5
      SK=FLOAT(K)
      T1=(S-Z)/SQRT(Z)
      T2=(S-Z-1.0)/SQRT(Z)
      CALL MDNOR(T1,C1)
      CALL MDNOR(T2,C2)
      MODGRE=(E/C)*(1.-C2)
      GRE=(SK/Z)*(1.-C1)+C2
C *** ARBITRARY STOPPING TO PREVENT WASTING BUDGET.
   11 IF(GRE.GT.0.9999)STOP=1
      RETURN
      END
C
      SUBROUTINE PRTOUT(MD,NAME,BR,MR,N,E,X,Z,C,PLT,INS,OV,TOV,NOBJ,
     *INDEX,STOP,NN1,NNN)
C *** ROUTINE TO PRINT OUT RESULTS
      INTEGER NOBJ,X(N),MD,STOP(N),INDEX(N),XL(500),NN1,NNN,INS(N)
      REAL Z(N),E(N),OV(NOBJ,N),TOV(NOBJ),PLT(N),MR,C(N)
      REAL*8 NAME(3),B,BR
      COMMON SN(500,9)
      DO 5 I=1,N
    5 XL(I)=Z(I)+0.5
      CALL OBJECT(X,N,Z,PLT,INS,OV,TOV,NOBJ,E,ASOSMA)
      WRITE(6,101)
      WRITE(6,102) MD,NAME,BR,MR,NN1,NNN
```

```
   13 WRITE(6,200)
  200 FORMAT('0',5X,'NIIN',5X,'DEPTH',4X,'GR-EFF',4X,'MSRT(DAYS)',
     *4X,'UNIT COST',2X,'PROB-VAR',3X,'LOBD?',2X,'UPBD?')
      WRITE(6,100)((SN(I,J),J=1,9),X(I),(OV(J,I),J=1,NOBJ),C(I),Z(I),
     *INDEX(I),STOP(I),I=1,N)
  100 FORMAT(3X,9A1,I7,1X,F10.4,F12.3,4X,F10.2,3X,F8.3,1X,I4,4X,I4)
      WRITE(6,103) (TOV(I),I=1,NOBJ)
      WRITE(6,105)ASOSMA
      WRITE(6,104)
  101 FORMAT('1','*****************************************************
     ******************************')
  102 FORMAT('0',1X,'MODEL (',I1,') ',3A8,2X,'BUDGET LEFT: $',F10.2,
     * //'  SHADOW COST: ',F12.8,11X,'ITERATIONS: ',I2,2X,
     *'(MAX ITERS: ',I2,' )')
  103 FORMAT('0',1X,'OVERALL PERFORMANCE:',F8.4,F12.3)
  105 FORMAT('0',1X,'            ASO SMA:',F8.4)
  104 FORMAT('-','*****************************************************
     ******************************')
      RETURN
      END
C
C *** ROUTINE TO COMPUTE THE OBJECTIVE FUNCTIONS FOR GIVEN ALLOCATION
      SUBROUTINE OBJECT(X,N,Z,PLT,INS,OV,TOV,NOBJ,E,ASOSMA)
      INTEGER N,NOBJ,X(N),XI,INS(N)
      REAL Z(N),OV(NOBJ,N),TOV(NOBJ),SLT,PLT(N),E(N),MSRT
      REAL S,T1,T2,CD,P,MSRTC,C1,C2,SXI,ESHORT(500),SHORT,MEAN1,MTOT
      REAL SMASO,GRE,ASOSMA
      DO 5 I=1,NOBJ
    5 TOV(I)=0.
      SLT=0.
      MTOT=0.0
      MEAN1=0.0
      SHORT=0.0
      GRE=0.0
      DO 20 I=1,N
          IF(INS(I).EQ.1)GO TO 17
          IF(Z(I).EQ.0.0)GO TO 16
          XI=X(I)
          SLT = SLT + Z(I)*E(I)
          MEAN1=Z(I)*4.0/PLT(I)
          MTOT=MTOT + MEAN1
          OV(1,I)=0.
C *** THE NEXT EQ. IS MSRT FOR X=0.
          MSRT=PLT(I)/2
          ESHORT(I)=MEAN1
          IF(XI .EQ. 0) GO TO 18
          IF(Z(I).GE.20.)GO TO 14
          CALL CDFP(Z(I),XI,P,CD)
          IF(CD.GT.0.999999)GO TO 16
          GRE=(Z(I)*(1.-P)+(XI-Z(I))*(1.-CD))/Z(I)
          CALL CDFP(MEAN1,XI,P,CD)
          SMASO=(MEAN1*(1-P)+(XI-MEAN1)*(1.-CD))/MEAN1
          GO TO 15
   14     S=FLOAT(XI)+0.5
```

```
            T1=(S-Z(I))/SQRT(Z(I))
            T2=(S-Z(I)-1.0)/SQRT(Z(I))
            CALL MDNOR(T1,C1)
            CALL MDNOR(T2,C2)
            SXI=FLOAT(XI)
            GRE=(SXI/Z(I))*(1.-C1)+C2
            T3=(S-MEAN1)/SQRT(MEAN1)
            T4=(S-MEAN1-1.0)/SQRT(MEAN1)
            CALL MDNOR(T3,C1)
            CALL MDNOR(T4,C2)
            SMASO=(SXI/MEAN1)*(1.-C1)+C2
   15       ESHORT(I)=MEAN1*(1.-SMASO)
            MSRTC=TWUS(Z(I),PLT(I),XI)/Z(I)
            MSRT=AMAX1(MSRTC,0.0)
            OV(1,I)=AMIN1(GRE,1.0)
            GO TO 18
   16       OV(1,I)=1.0
            SMASO=1.0
            ESHORT(I)=0.0
            MSRT=0.0
            GO TO 18
   17       OV(1,I)=0.0
            MSRT=100.0
            ESHORT(I)=0.0
            Z(I)=0.0
   18       OV(2,I) = 91.*MSRT
            TOV(1) = TOV(1) + OV(1,I)*Z(I)*E(I)
            TOV(2) = TOV(2) + OV(2,I)*Z(I)*E(I)
   20 CONTINUE
      DO 21 I=1,N
   21 SHORT=SHORT+ESHORT(I)
      TOV(1)=TOV(1)/SLT
      TOV(2)=TOV(2)/SLT
      ASOSMA=1.-SHORT/MTOT
      RETURN
      END
C
      INTEGER FUNCTION NFX(ZZ,S,RISK)
C *** ROUTINE TO FIND MIN X SUCH THAT CDF(X).GE.(1-RISK)
      REAL ZZ,R,RISK,TT,S
      INTEGER NX,NB
      R=1.-RISK
      NX=0
C *** DO WHILE(CDF(NX).LT.R). ASO USES THE POISSON DISTRIBUTION IF ZZ
C *** IS LESS THAN 4, OTHERWISE THE NORMAL IS USED.
      IF(ZZ.GE.4.)GO TO 11
   10 CALL CDFP(ZZ,NX,P,C)
      IF(C.GE.R) GO TO 20
      NX=NX+1
      GO TO 10
   20 NFX=NX
      RETURN
   11 CALL CDFN(R,TT)
      NFX=ZZ+TT*S+0.9999
```

```
      RETURN
      END
C
      SUBROUTINE CDFP(ZZ,K,P,C)
C *** ROUTINE TO CALCULATE POISSON MASS AND CUMULATIVE DISTRIBUTION
C *** FUNCTIONS.
      REAL*8 ZZZ,PP,CC
      REAL ZZ,P,C
      INTEGER K,I
      ZZZ=ZZ
      PP=DEXP(-ZZZ)
      CC=PP
      IF(K.EQ.0)GO TO 11
      DO 10 I=1,K
      PP=PP*ZZZ/DFLOAT(I)
      CC=CC+PP
   10 CONTINUE
   11 P=PP
      C=CC
      RETURN
      END
C
      SUBROUTINE CDFN(R,TT)
C *** ROUTINE TO CALCULATE THE NORMAL DEVIATE TT FOR A GIVEN VALUE OF R
C   * THIS ROUTINE USES THE IMSL ROUTINE MDNRIS WHICH IS AVAILABLE ON
C *** THE NPS IBM 3033.
      INTEGER IER
      REAL R,TT
      CALL MDNRIS(R,TT,IER)
      RETURN
      END
```

APPENDIX B

SPCC INPUT DATA ELEMENTS

B.1 ITEM DATA ELEMENTS

1. Provisioning Control Number
2. Cognizance Code
3. Federal Supply Classification
4. Item Identification Number (NIIN)
5. Unit Price
6. Best Replacement Factor
7. Production Lead Time
8. Procurement Lead Time
9. Repairable Item Indicator
10. Source Code
11. Technical Override Indicator
12. Minimum Replacement Unit
13. File Indicator
14. New Item Indicator
15. Allowance Quantity
16. Time-Weighted Average Month's Program (Steady State)
17. Time-Weighted Average Month's Program (Initial)
18. System Recurring Demand Average
19. Repair Survival Rate
20. Repair Turn-Around-Time
21. Use Maintenance Code
22. Repair Maintenance Code
23. Recoverability Code
24. Allowance Override Quantity
25. Acquisition Advice Code

B.2 CONSTANT DATA ELEMENTS

1. Program Constants
   a. Cost of Procurement (Large Purchase)
   b. Cost of Procurement (Small Purchase)
   c. Large/Small Procurement Breakpoint
   d. Cost of Spot Procurement
   e. Spot Buy Premium Rate
   f. Holding Cost Rate
   g. Cost of Issuing Stock
   h. Standard Deviation Rule Coefficient
   i. Standard Deviation Rule Power
   j. Conditional Probabilities of No Demand

2. Cog Constants
   a. Carcass Return Rate
   b. Repair Survival Rate (Item Default Value)
   c. Production Lead Time (Item Default Value)
   d. Procurement Lead Time (Item Default Value)
   e. Repair Turn-Around-Time (Item Default Value)
   f. Shortage Cost for COSDIF Computation
   g. Shortage Cost for UICP Risk Computation
   h. Carcass Retrograde Time

APPENDIX C

SPCC COG CONSTANTS

COG	1H	7G	7H
Carcass Return Rate	0	0.86	0.76
Repair Survival Rate[1,2]	0	0.92	0.92
Production Lead Time[1,2]	4.12	5.07	5.13
Procurement Lead Time [1,2]	5.59	6.07	6.13
Repair Turn-Around-Time[1,2]	0	1.29	1.44
COSIDF Shortage Cost[3]	$350	$ 600	1000
UICP Shortage Cost	$700	$1200	2000
Carcass Retrograde Time[2]	0	0.92	0.99

1. Item Default Value (only used if an item has no value on the tape)
2. Time values are in quarters.
3. This is actually the product of item essentiality (E_i=0.5) and the UICP Shortage Cost.

APPENDIX D

SPCC CONSTANT DATA ELEMENTS

a.	Large Purchase Cost of Procurement	\$ 175
b.	Small Purchase Cost of Procurement	\$ 535
c.	Large/Small Procurement Breakpoint (value of annual demand)	\$8000
d.	Cost of Spot Procurement	\$ 450
e.	Spot Buy Premium Rate	0.33
f.	Holding Cost Rate; Consumables	0.23
	Repairables	0.21
g.	Cost of Issuing Stock	\$ 8

h. Standard Deviation Formula:

$$\sigma = 2.01(Z)^{.701}$$

where Z = mean demand during procurement lead time for consumables; mean attrition demand during procurement lead time plus demand during repair turn-around-time for repairables.

i. Conditional probabilities of No Demand (D_0/D_T)

D_T	D_0/D_T
0	0.7
1	0.59
2	0.49
3-12	0.32

where D_T= total steady state annual demand, based on $TWAMP_{SS}$

Above D_T = 12 the COSDIF formula is not used because the item is automatically considered to be demand-based.

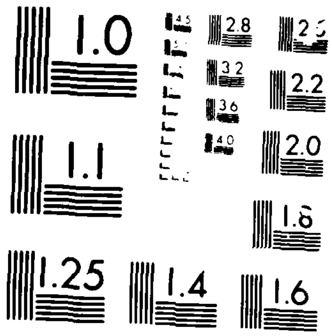
APPENDIX E

ASO ITEM INPUT DATA ELEMENTS

1. NIIN (ACN, PCC-ISN)
2. Unit Price, Replacement
3. Cognizance Code
4. Quantity Per Unit Pack
5. Source Code
6. Repairable Item Indicator
7. Program Related for Future Demand Indicator
8. Total Item Population
9. Total Item Population - Concurrent Rework
10. Total Item Population - F/J Reworks
11. Insurance Quantity
12. PAR Pool Quantity
13. TBI (Test Bench Installation) Quantity
14. System Recurring Demand Average (B022.
15. System Recurring Overhaul Demand Average (B022A)
16. System Carcass Return Average (B022B)
17. Maintenance Replacement Rate - Organization Level (F001)
18. Overhaul Replacement Rate (F003)
19. Wearout Rate
20. Repair Survival Rate (F009)
21. Procurement Lead Time Forecast

AD-A168 933   WHOLESALE PROVISIONING MODELS: MODEL EVALUATION(U)   2/2
NAVAL POSTGRADUATE SCHOOL MONTEREY CA   A W MCMASTERS
MAY 86 NPS55-86-011

UNCLASSIFIED   F/G 15/5   NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

APPENDIX F

SAMPLE OUTPUT OF SPCC DATA PREVIEW

```
        **********************************************************************

        ******     END ITEM : AN/UYK-21            POPULATION :   54     ******

        **********************************************************************

REPAIR PART: LAMPHOLDER          COG:          1H   PRICE:$      11.20(EA)  NIIN:        010624525

BRF:  0.0300   QTY/APPLIC:    0   THAMPI:      142   SOURCE CODE:        PA  MRU:                 1

THAMPSS:  392  WHSL DEPTH:    9   PCLT:  5.70 QTRS  PROD LEADTIME: 4.0 QTRS  LEADTIME DEMAND:     7

               ALLOW. QTY:    0   SURVIVE RATE:0.0   REPAIR TAT:       0.0

REPAIRABLE?:N  TOR(NSO)?:     Z   SPCC MANAGED?: M   NEW ITEM?           M   (M = YES)

REPAIR PART: NETWORK             COG:          1H   PRICE:$       2.34(EA)  NIIN:         LLMC09296

BRF:  0.0069   QTY/APPLIC:    0   THAMPI:       25   SOURCE CODE:        PA  MRU:                 1

THAMPSS:  130  WHSL DEPTH:    1   PCLT:  5.00 QTRS  PROD LEADTIME: 3.0 QTRS  LEADTIME DEMAND:     1

               ALLOW. QTY:    0   SURVIVE RATE:0.0   REPAIR TAT:       0.0

REPAIRABLE?:N  TOR(NSO)?:     Z   SPCC MANAGED?: M   NEW ITEM?           M   (M = YES)

REPAIR PART: COIL,RF             COG:          1H   PRICE:$       3.02(EA)  NIIN:         LLMC07303

BRF:  0.0029   QTY/APPLIC:    0   THAMPI:       37   SOURCE CODE:        PA  MRU:                 1

THAMPSS:   77  WHSL DEPTH:    1   PCLT:  4.92 QTRS  PROD LEADTIME: 4.9 QTRS  LEADTIME DEMAND:     1

               ALLOW. QTY:    0   SURVIVE RATE:0.0   REPAIR TAT:       0.0

REPAIRABLE?:N  TOR(NSO)?:     Z   SPCC MANAGED?: M   NEW ITEM?           M   (M = YES)

REPAIR PART: COIL,RF             COG:          1H   PRICE:$       8.42(EA)  NIIN:         LLMC07305

BRF:  0.0029   QTY/APPLIC:    0   THAMPI:      111   SOURCE CODE:        PA  MRU:                 1

THAMPSS:  231  WHSL DEPTH:    1   PCLT:  4.70 QTRS  PROD LEADTIME: 3.0 QTRS  LEADTIME DEMAND:     1

               ALLOW. QTY:    0   SURVIVE RATE:0.0   REPAIR TAT:       0.0

REPAIRABLE?:N  TOR(NSO)?:     Z   SPCC MANAGED?: M   NEW ITEM?           M   (M = YES)

REPAIR PART: MICRO CKT, DGTL     COG:          1H   PRICE:$      43.00(EA)  NIIN:         LLMB97686

BRF:  0.0100   QTY/APPLIC:    0   THAMPI:      203   SOURCE CODE:        PA  MRU:                 1

THAMPSS:  936  WHSL DEPTH:    4   PCLT:  4.40 QTRS  PROD LEADTIME: 2.7 QTRS  LEADTIME DEMAND:     3

               ALLOW. QTY:    0   SURVIVE RATE:0.0   REPAIR TAT:       0.0

REPAIRABLE?:N  TOR(NSO)?:     Z   SPCC MANAGED?: M   NEW ITEM?           M   (M = YES)
```

APPENDIX G

GRAPHS OF BUDGET FOR VARIOUS MSRT GOALS

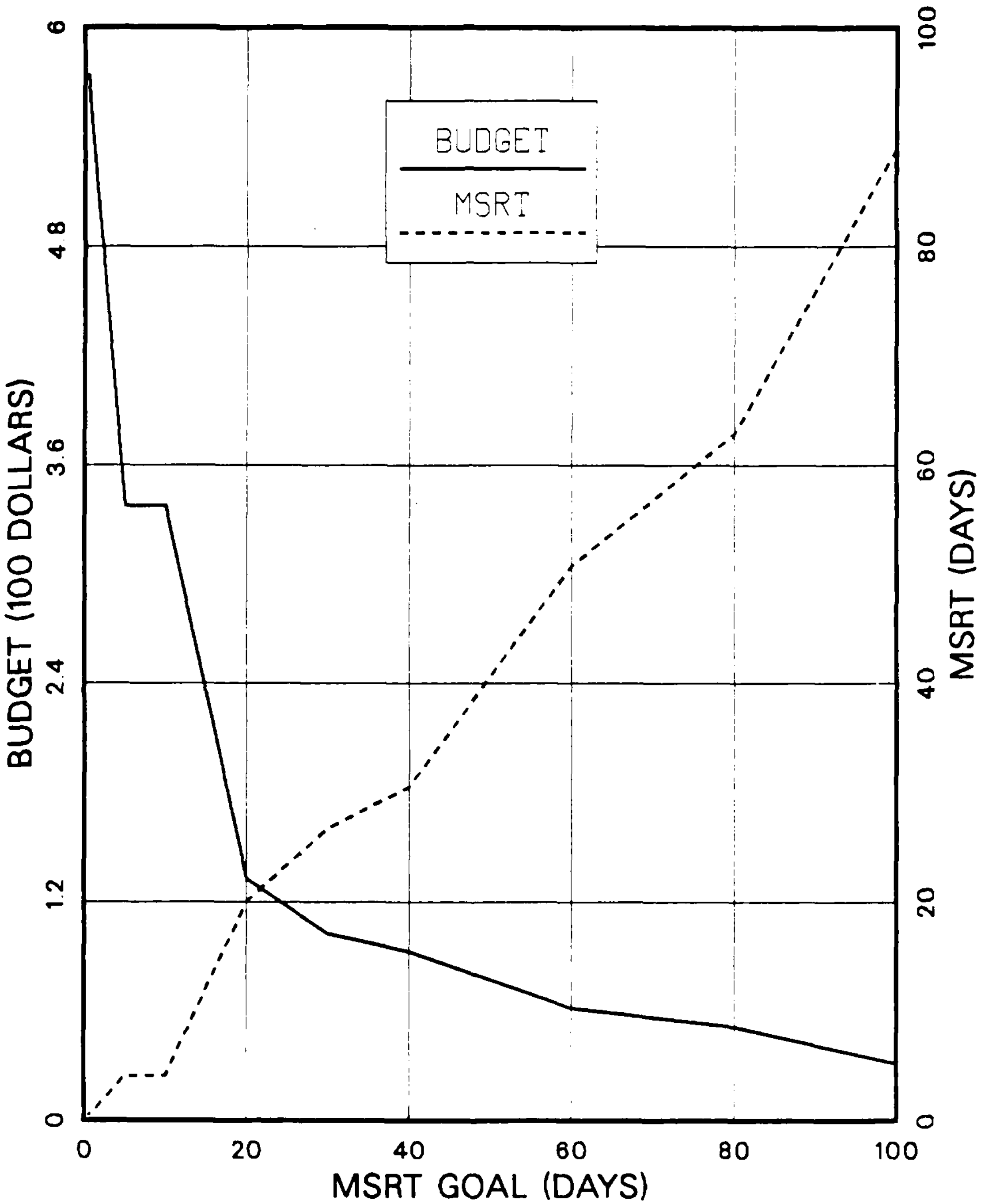


Figure G.1. 2WVO/1H; Marginal analysis budget and MSRT values for a range of MSRT goals.

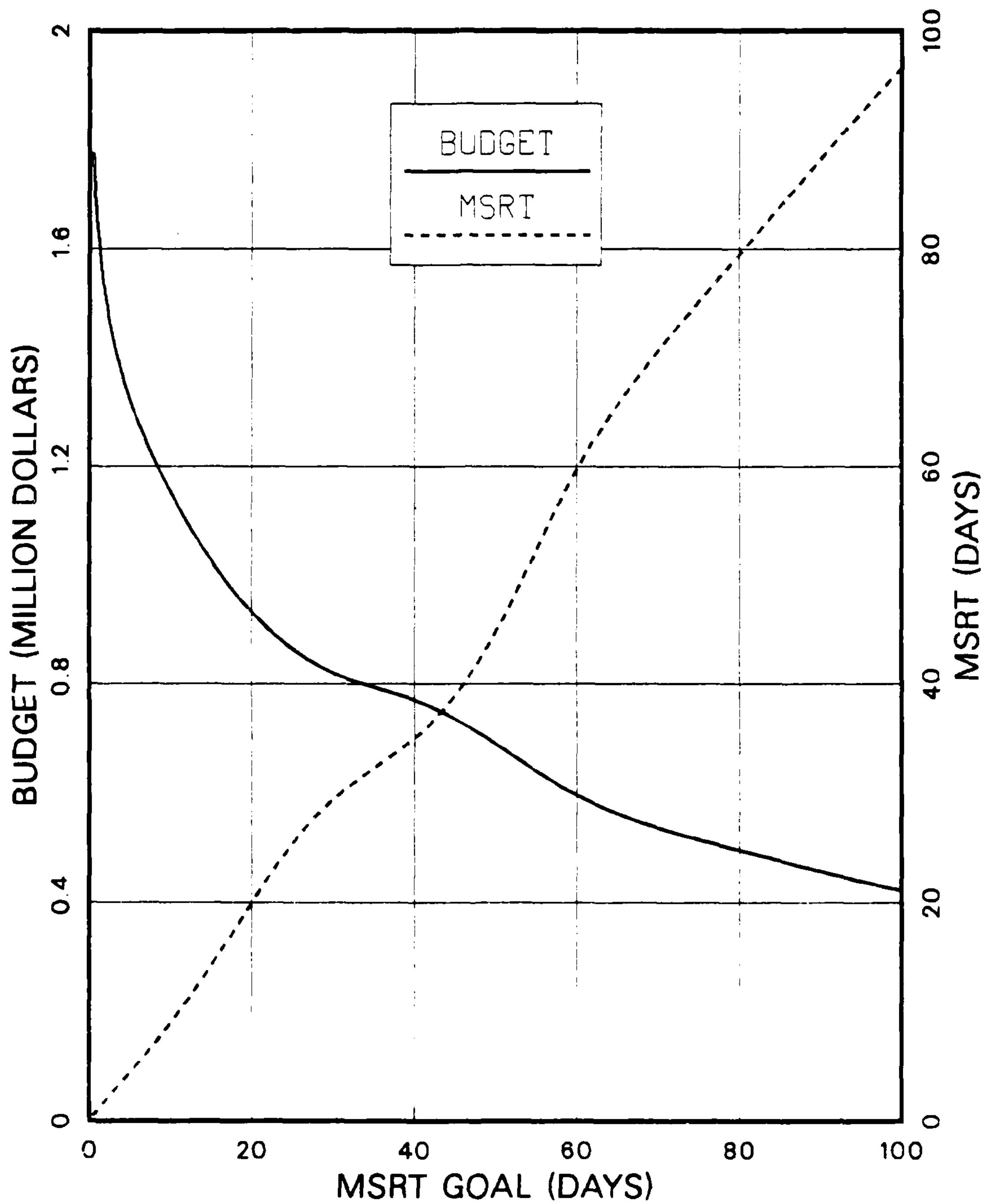


Figure G.2. BEHA/7G; Marginal analysis budget and MSRT values for a range of MSRT goals.

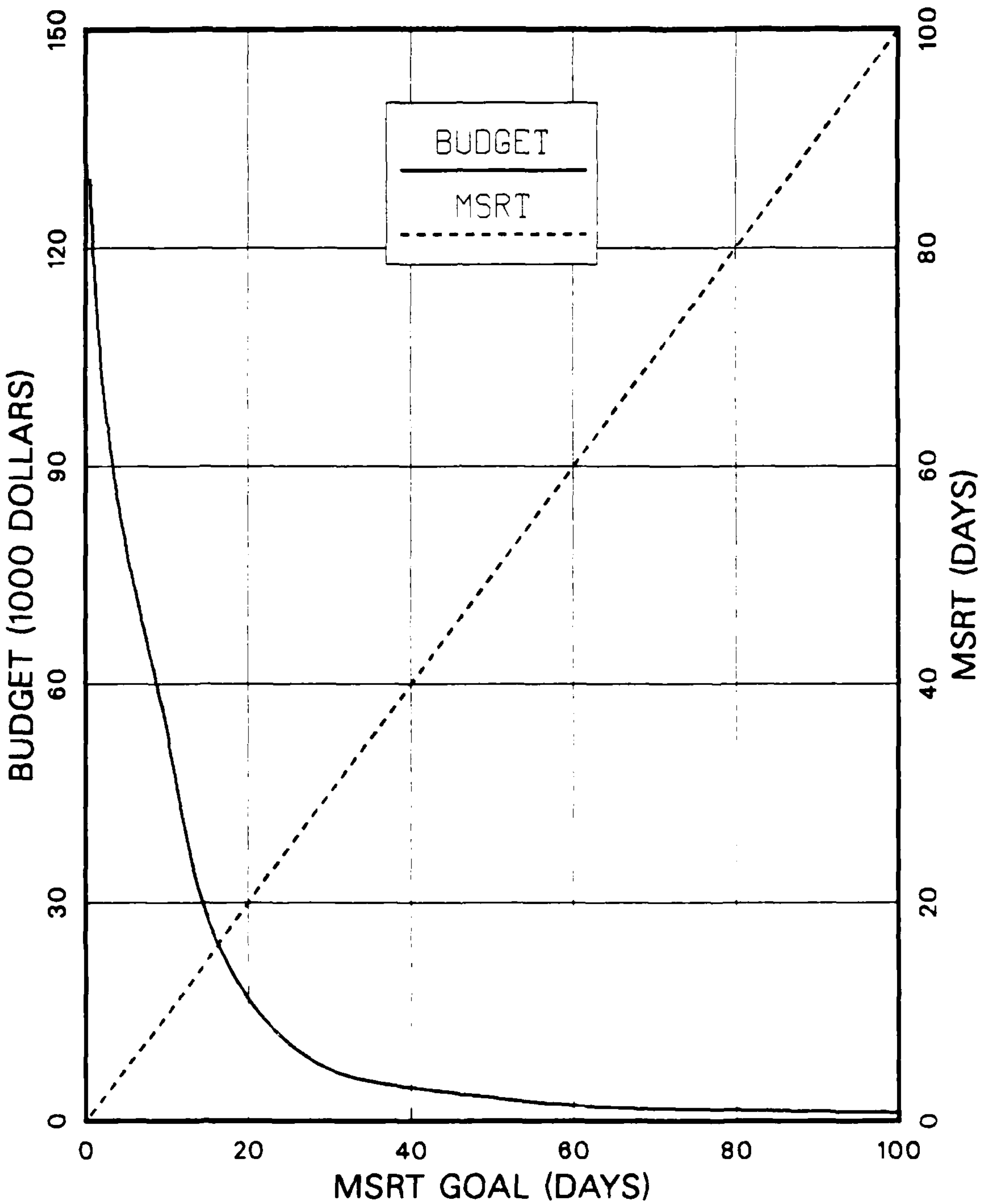


Figure G.3. 5EZO/1H; Marginal analysis budget and MSRT values for a range of MSRT goals.

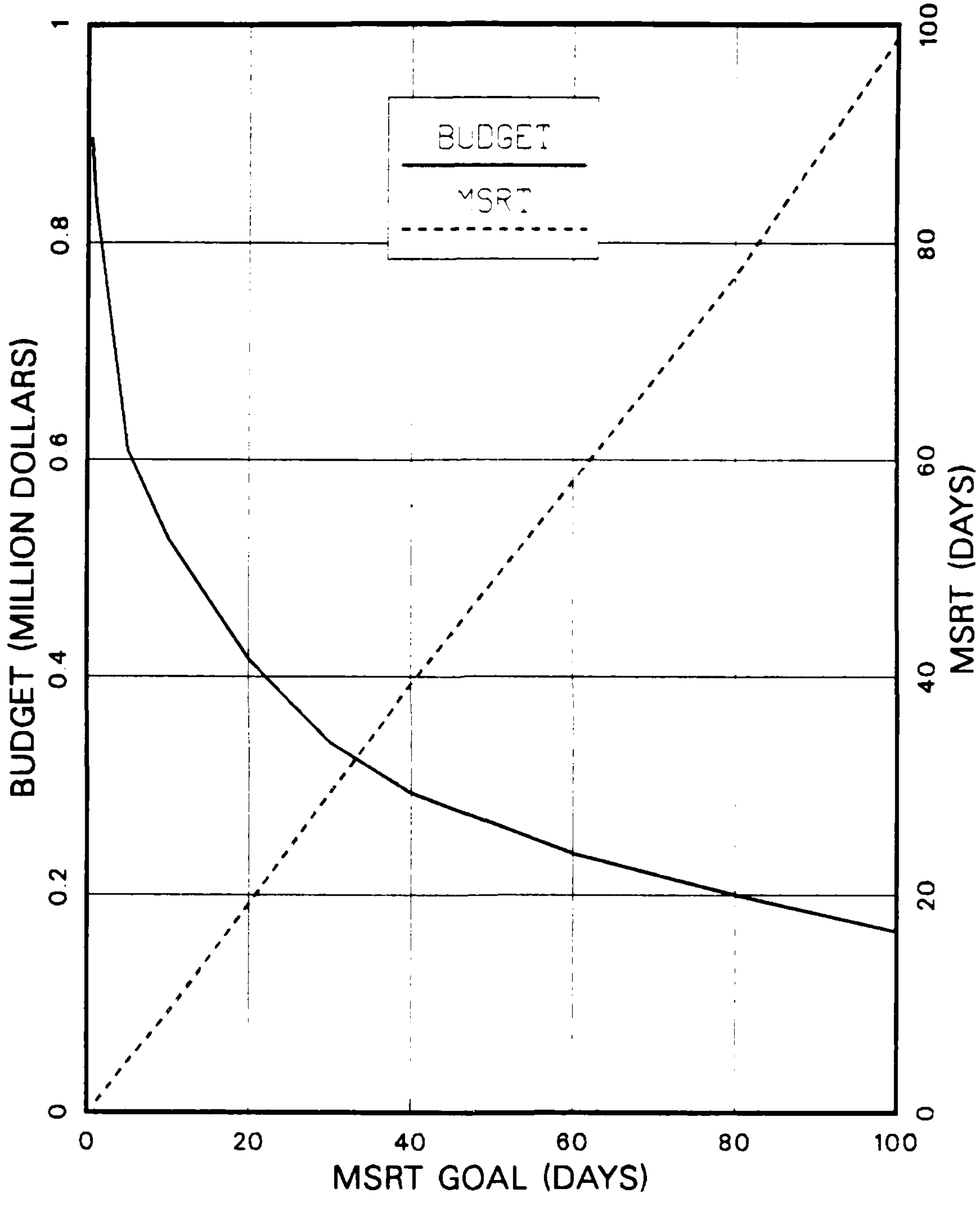


Figure G.4. 5EZO/7G; Marginal analysis budget and MSRT values for a range of MSRT goals.

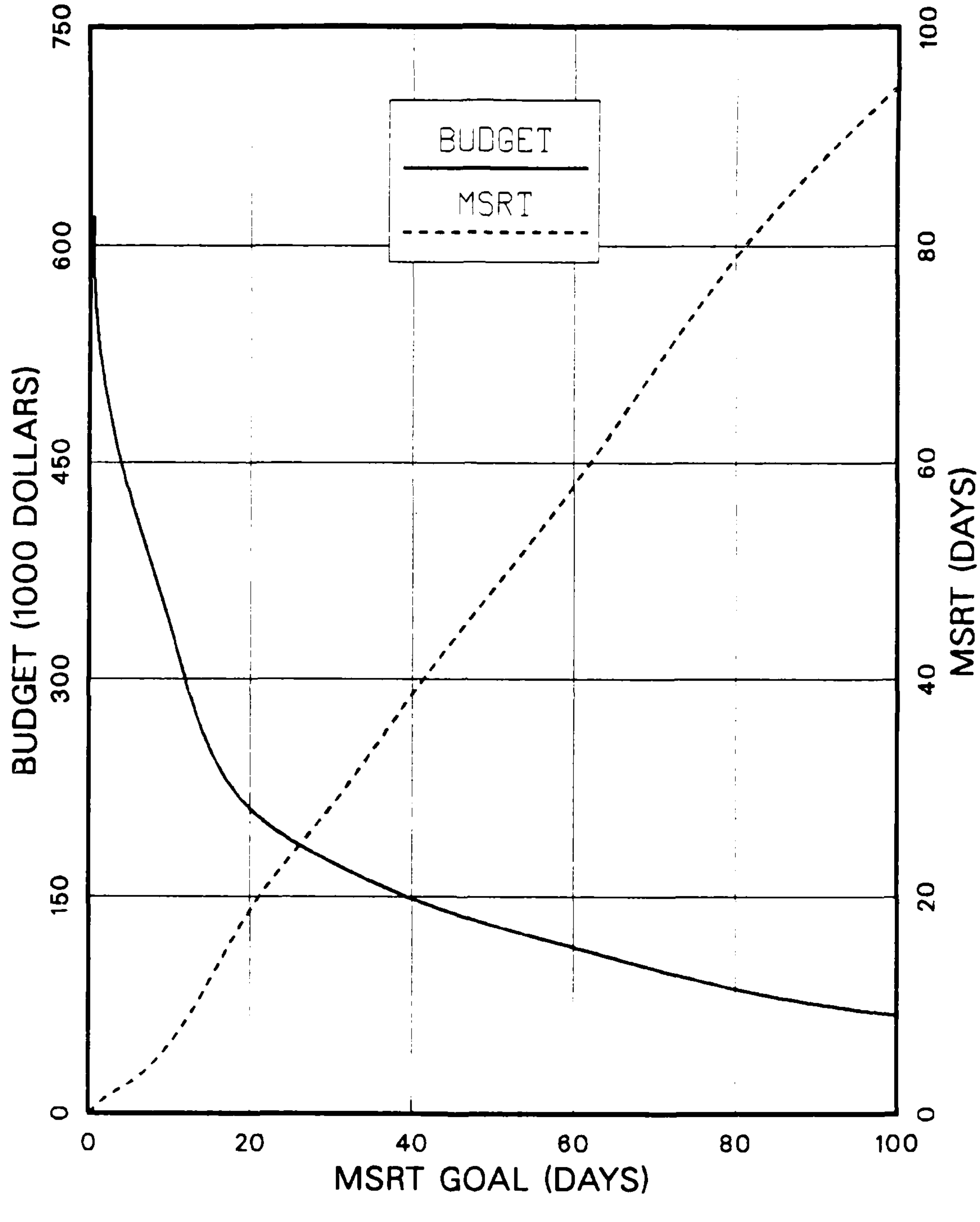


Figure G.5. RDMA/1H; Marginal analysis budget and MSRT values for a range of MSRT goals.

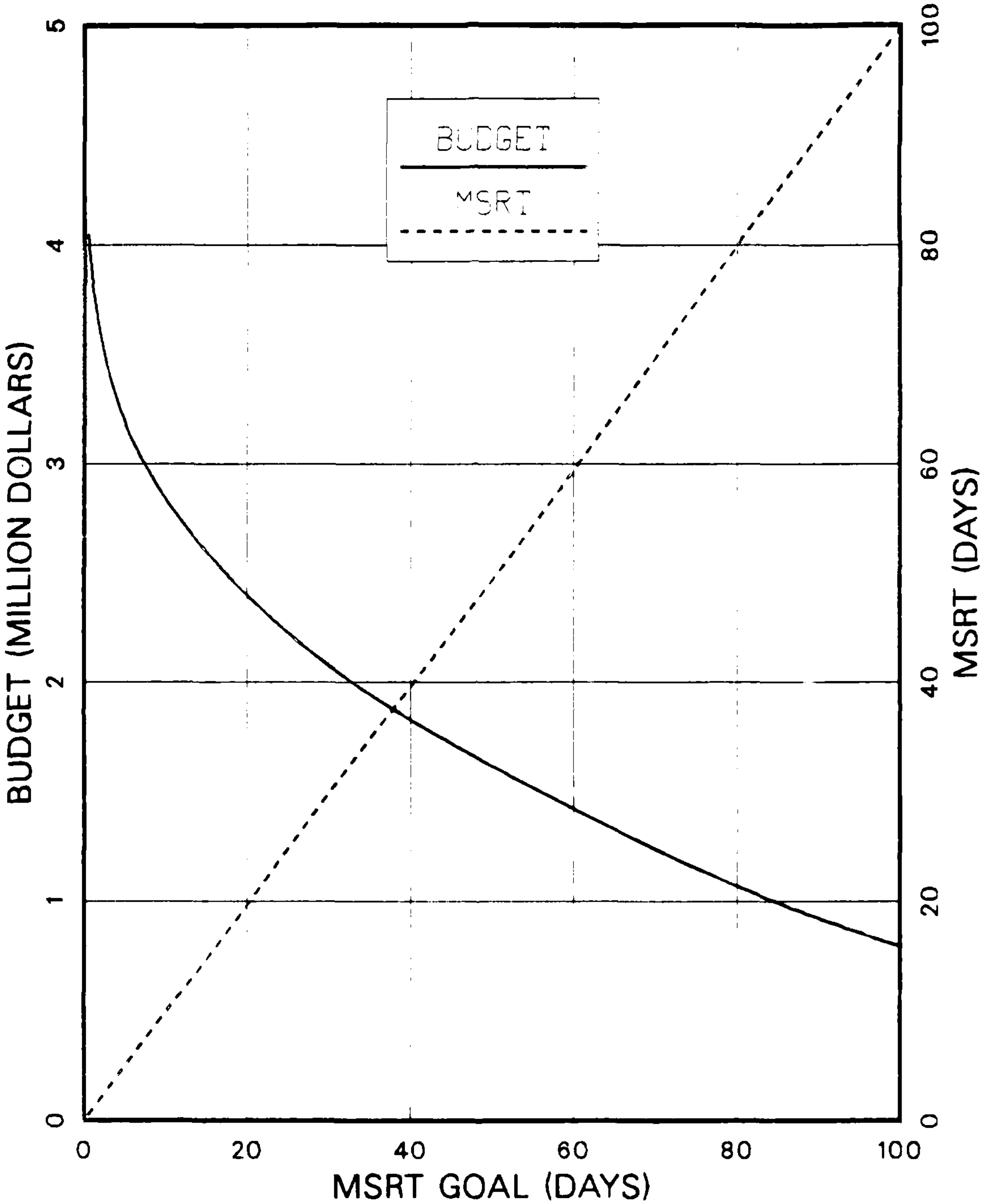


Figure G.6. RDMA/7H; Marginal analysis budget and MSRT values for a range of MSRT goals.

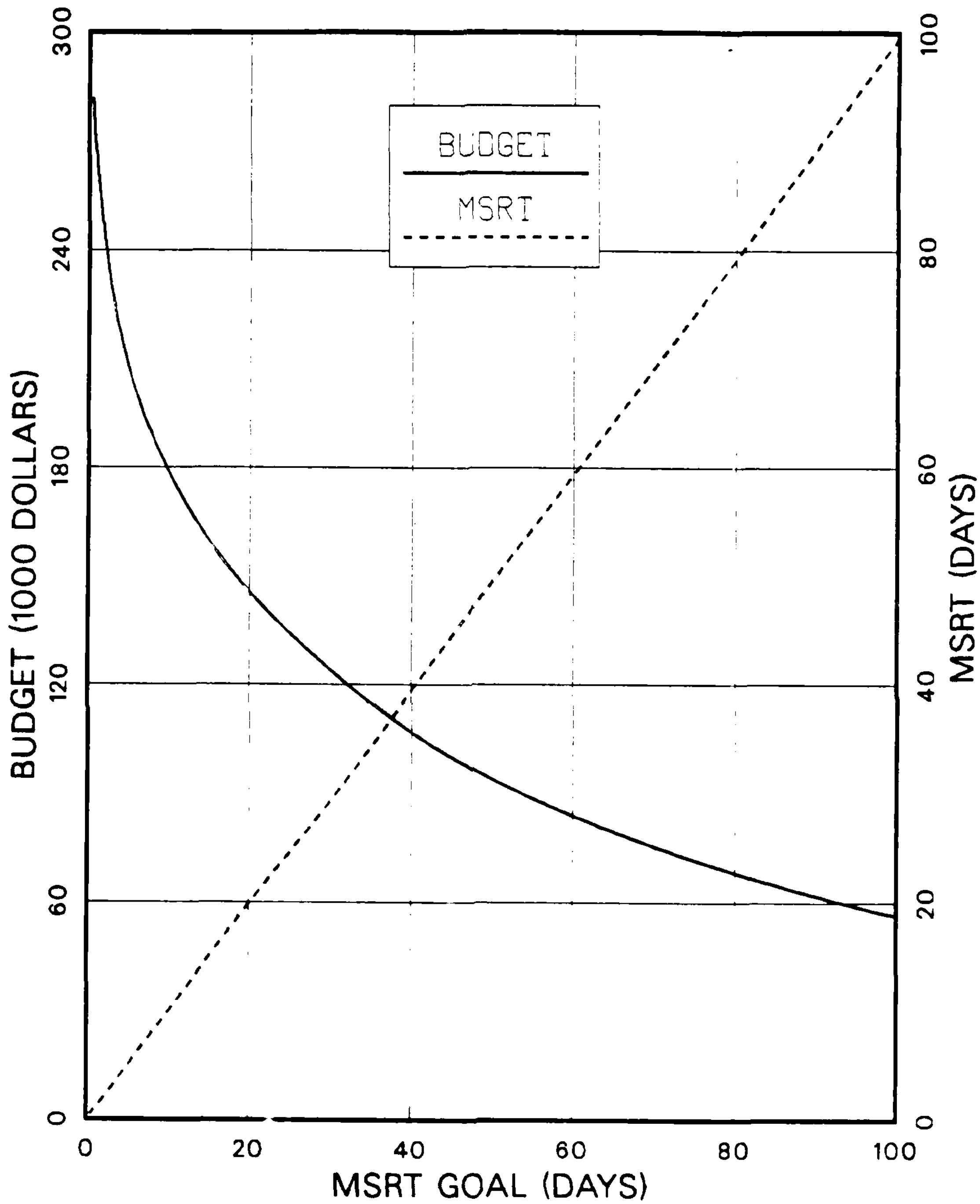


Figure G.7. T3HE/1H; Marginal analysis budget and MSRT values for a range of MSRT goals.

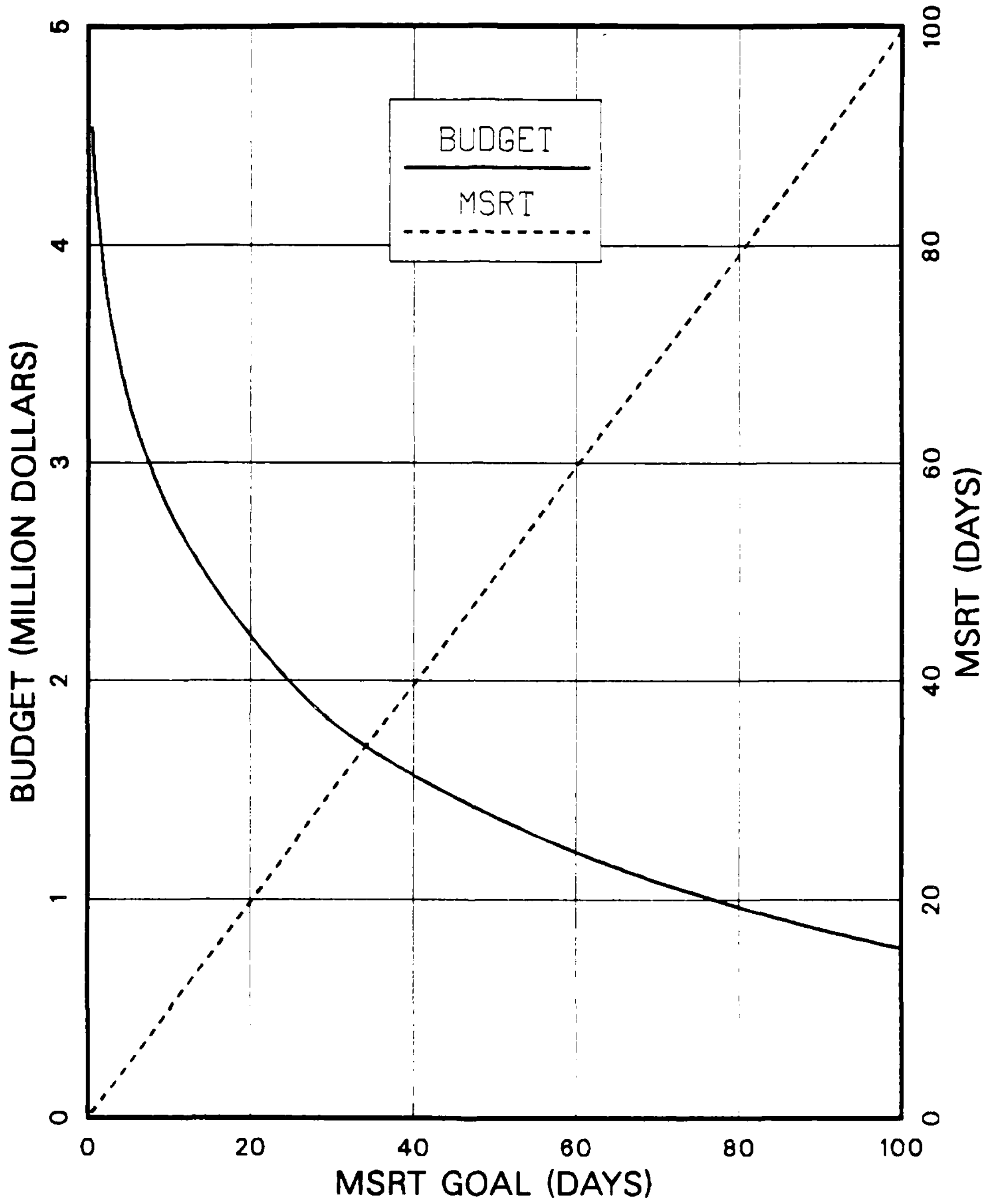


Figure G.8. T3HE/7G; Marginal analysis budget and MSRT values for a range of MSRT goals.

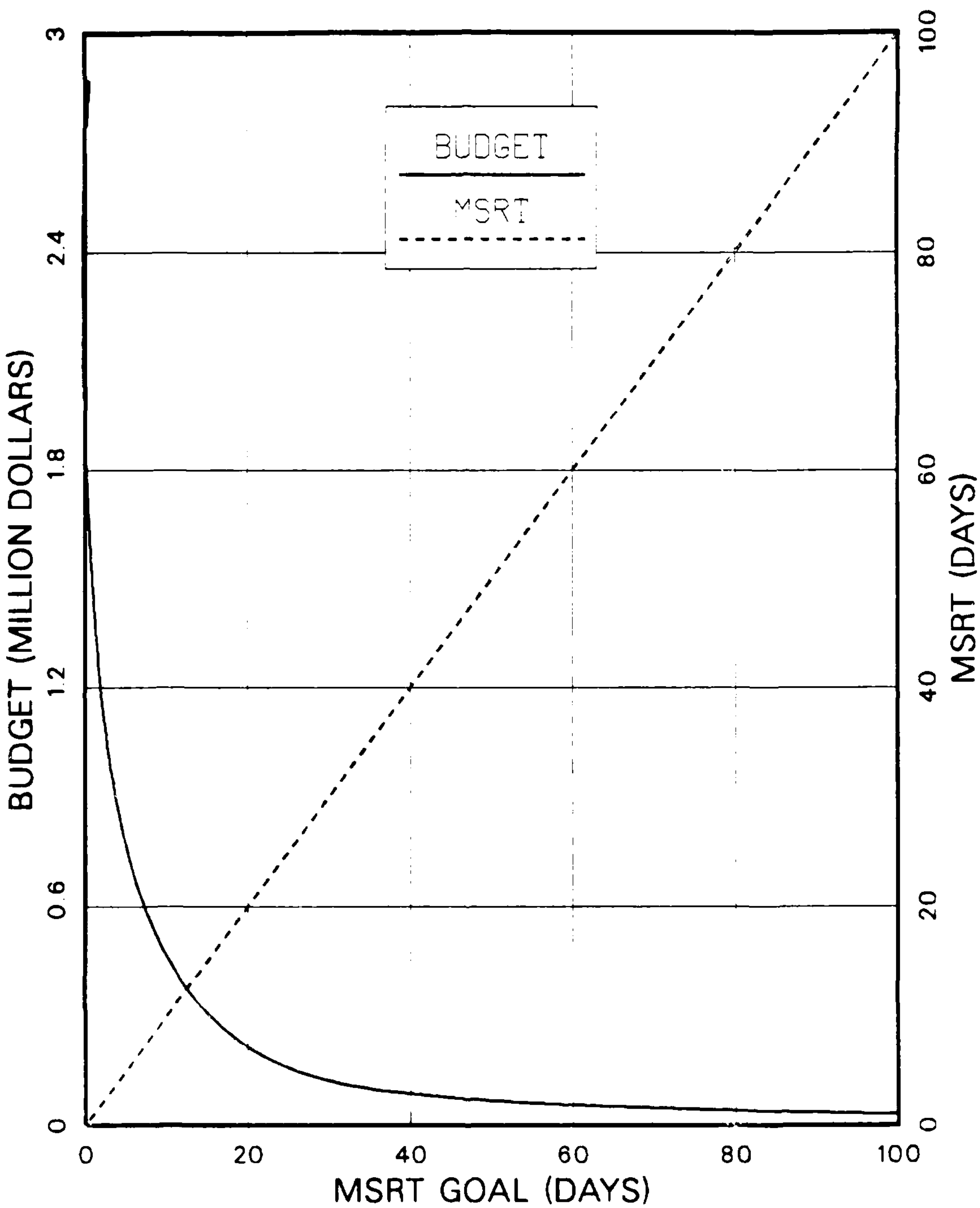


Figure G.9. RDRA/1H; Marginal analysis budget and MSRT values for a range of MSRT goals.

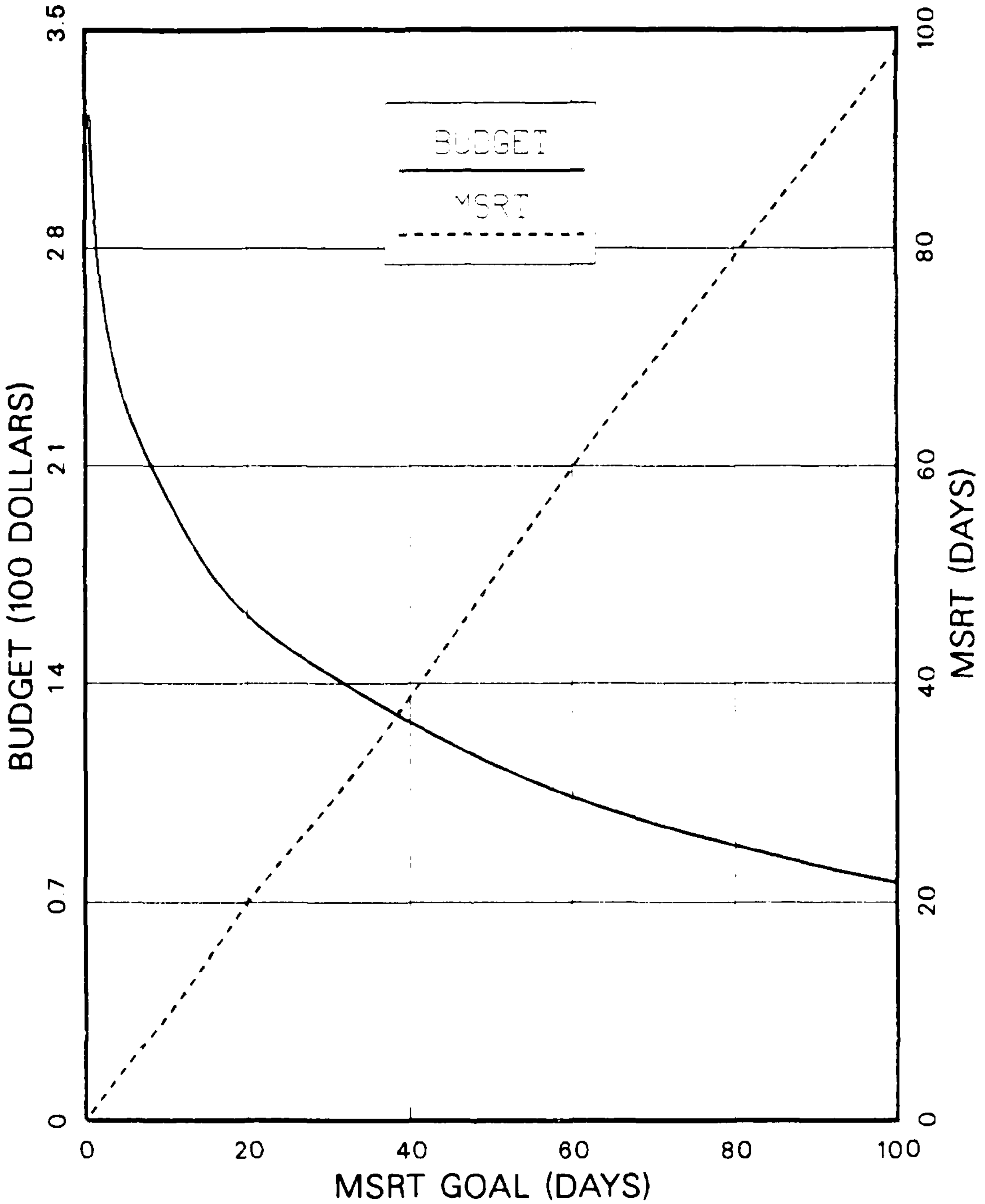


Figure G.10. RDRA/7H: Marginal analysis budget and MSRT values for a range of MSRT goals.

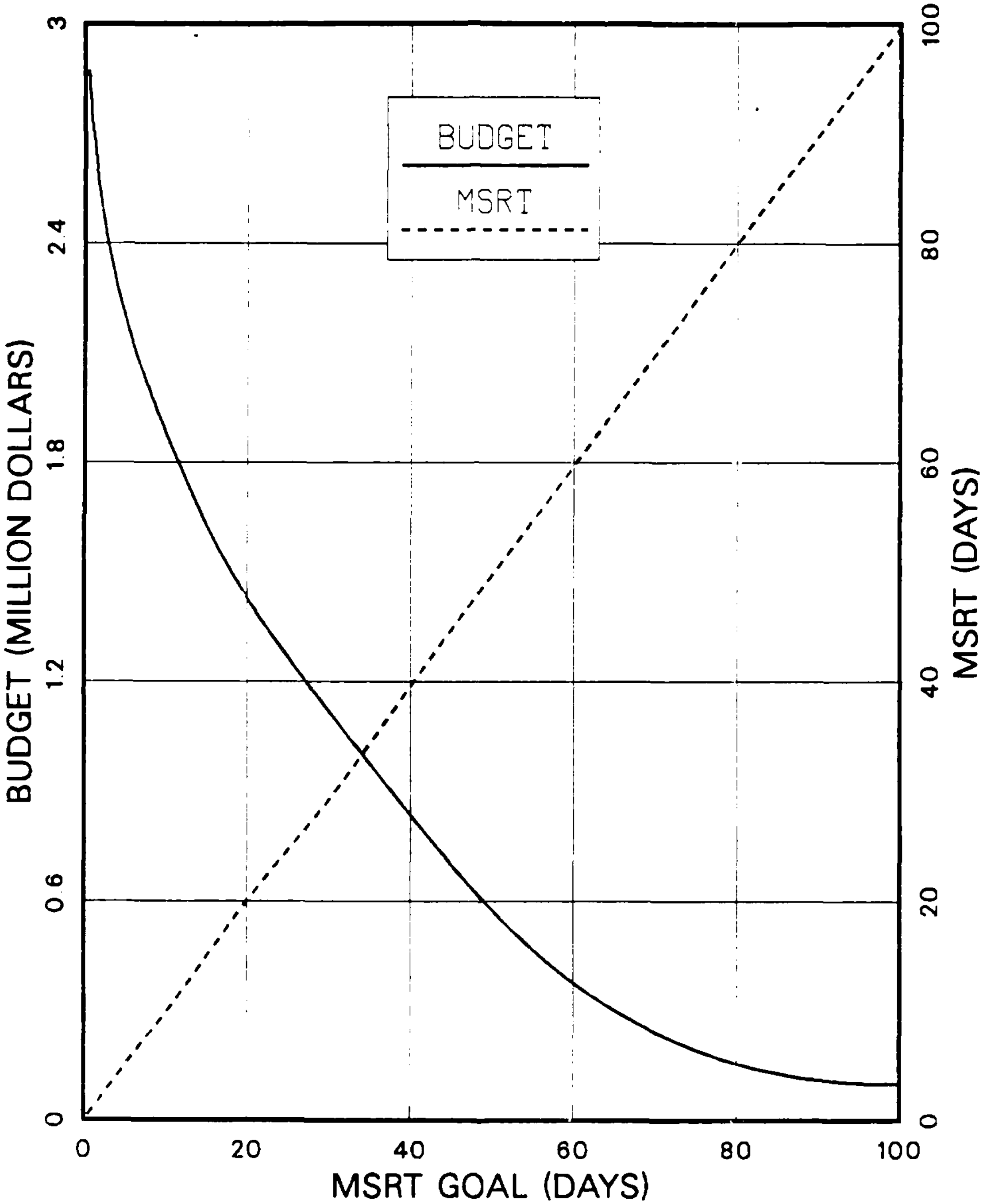


Figure G.11. RDSA/1H; Marginal analysis budget and MSRT values for a range of MSRT goals.

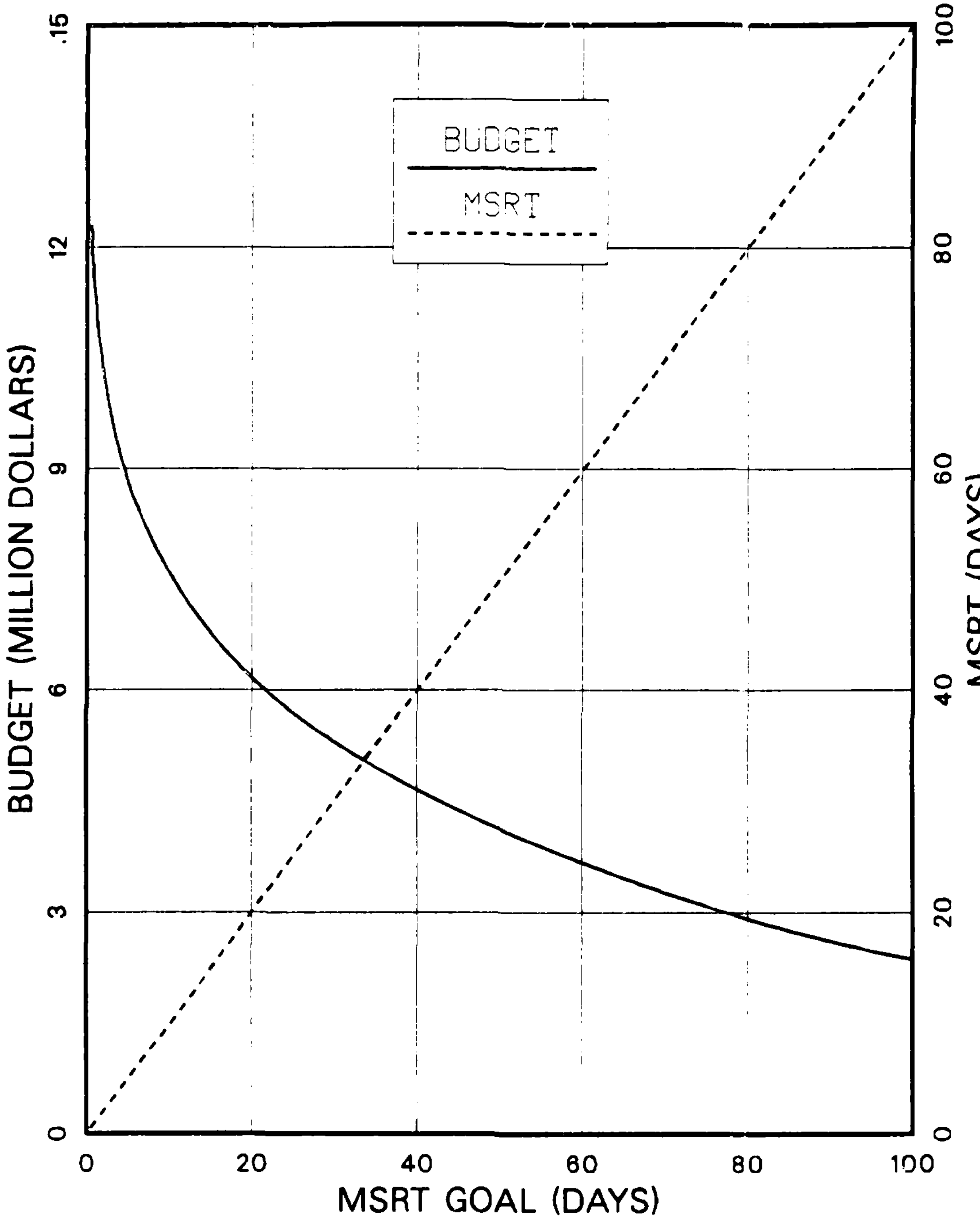


Figure G.12. RDSA/7H; Marginal analysis budget and MSRT values for a range of MSRT goals.

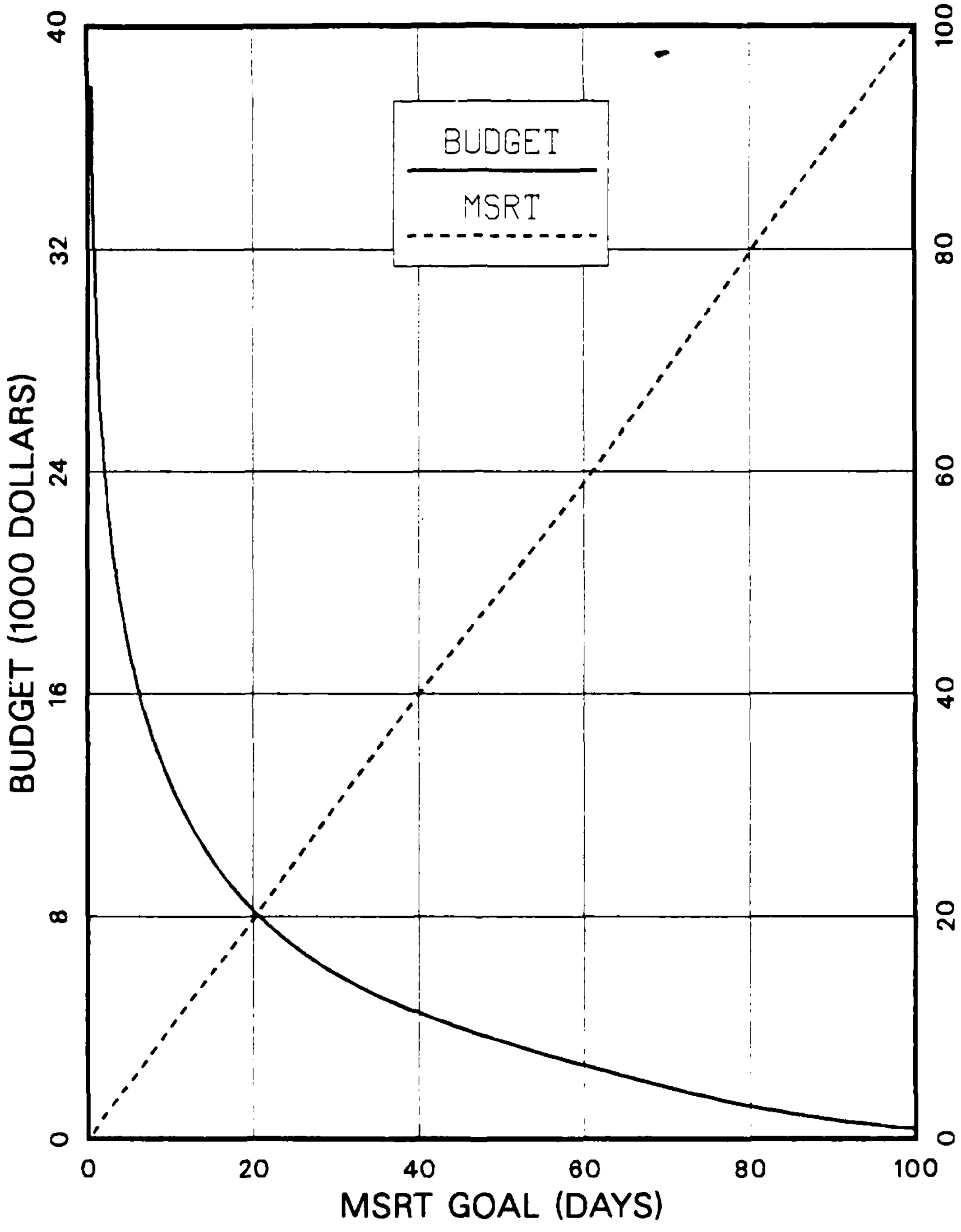


Figure G.13. PBV/1R; Marginal analysis budget and MSRT values for a range of MSRT goals.

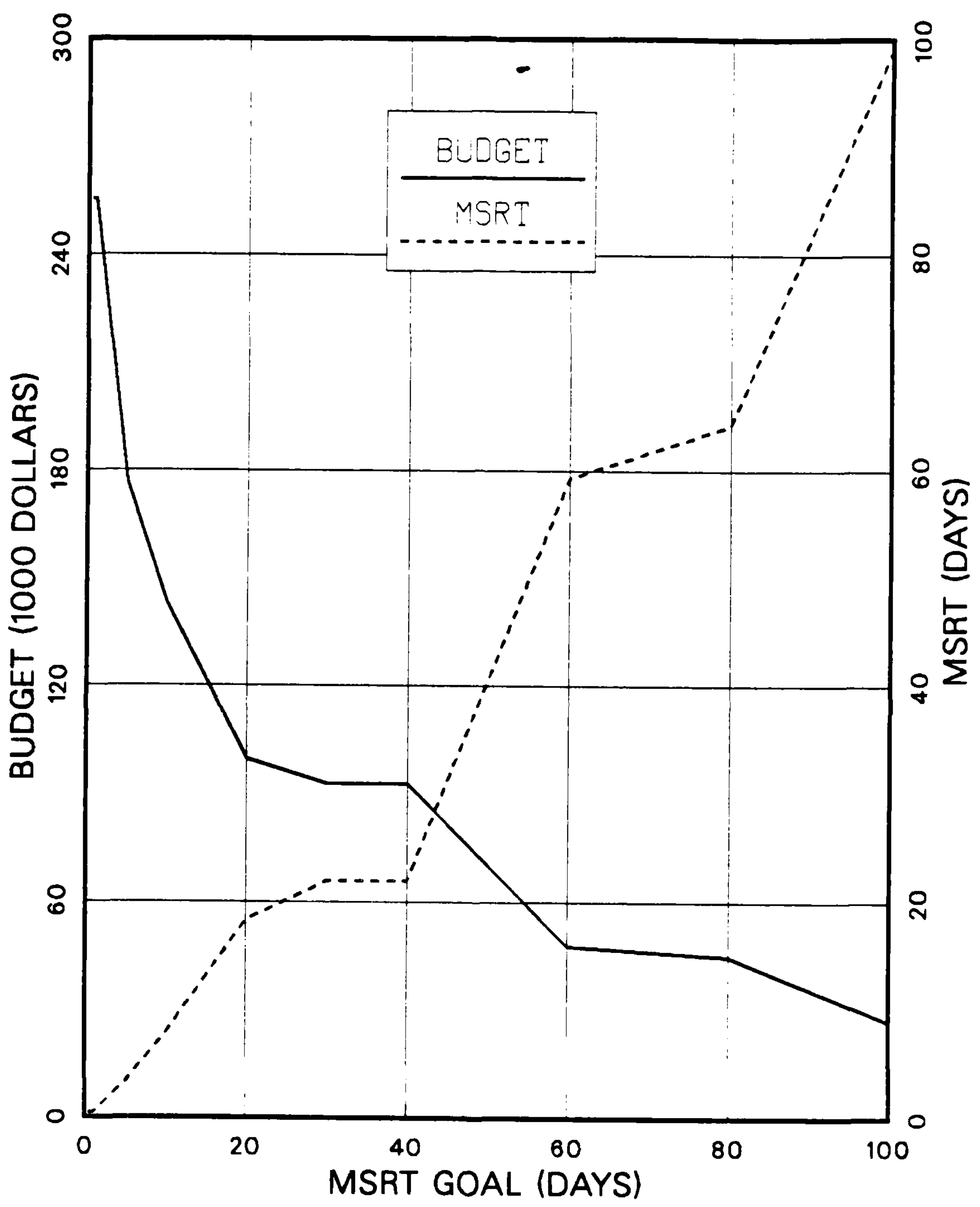


Figure G.14. PBV/2R; Marginal analysis budget and MSRT values for a range of MSRT goals.

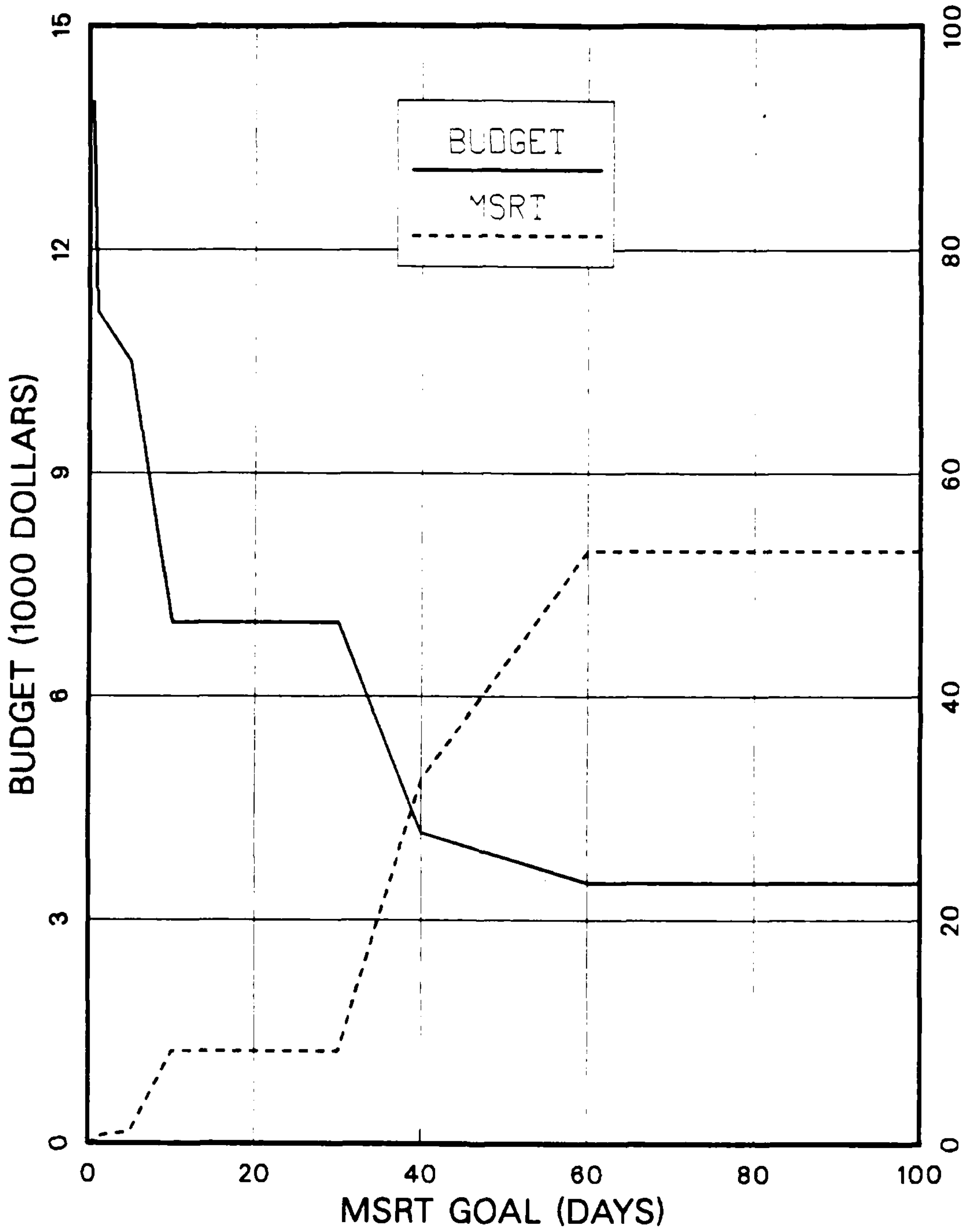


Figure G.15. PBT/1R; Marginal analysis budget and MSRT values for a range of MSRT goals.

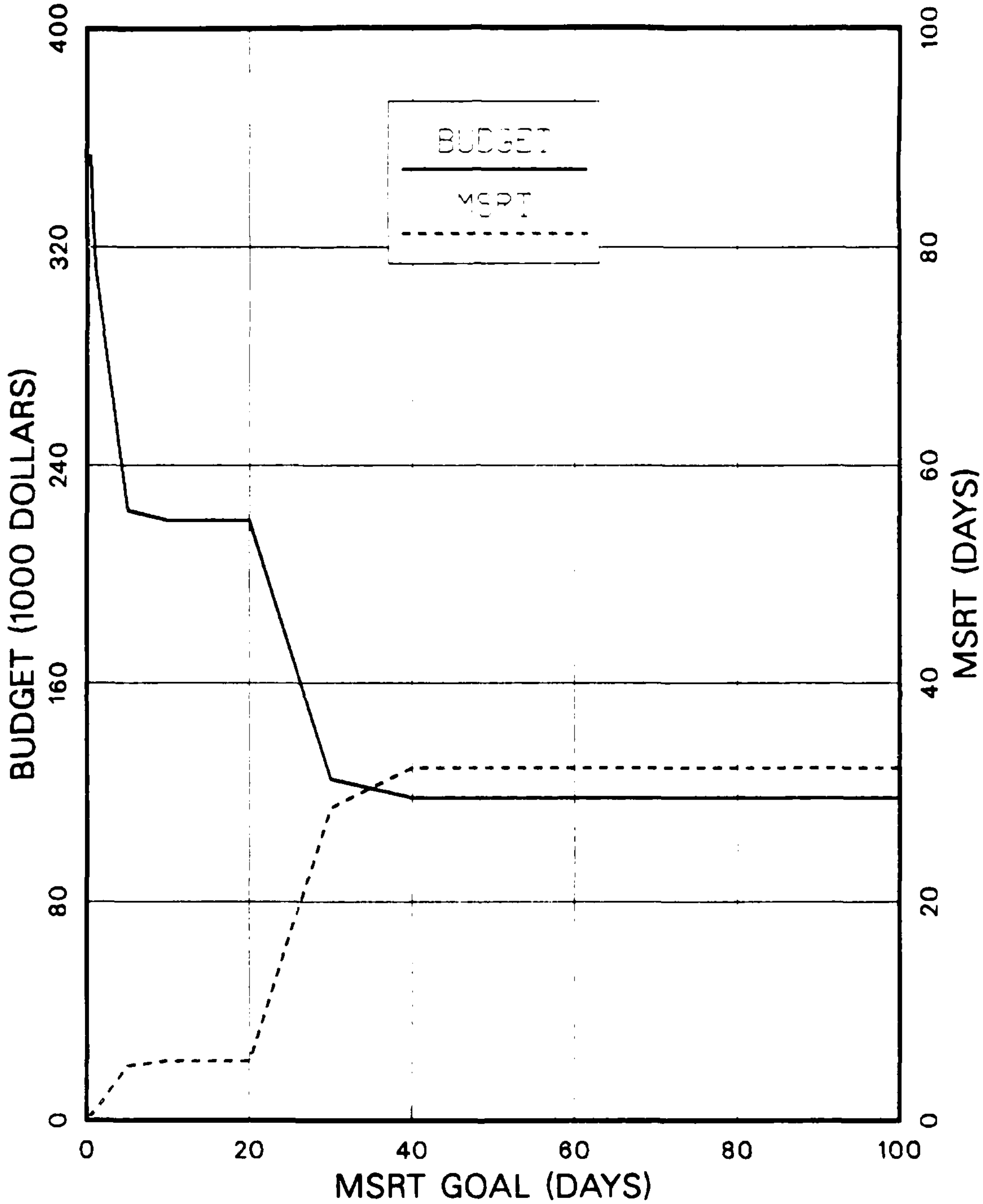


Figure G.16. PBT/2R; Marginal analysis budget and MSRT values for a range of MSRT goals.

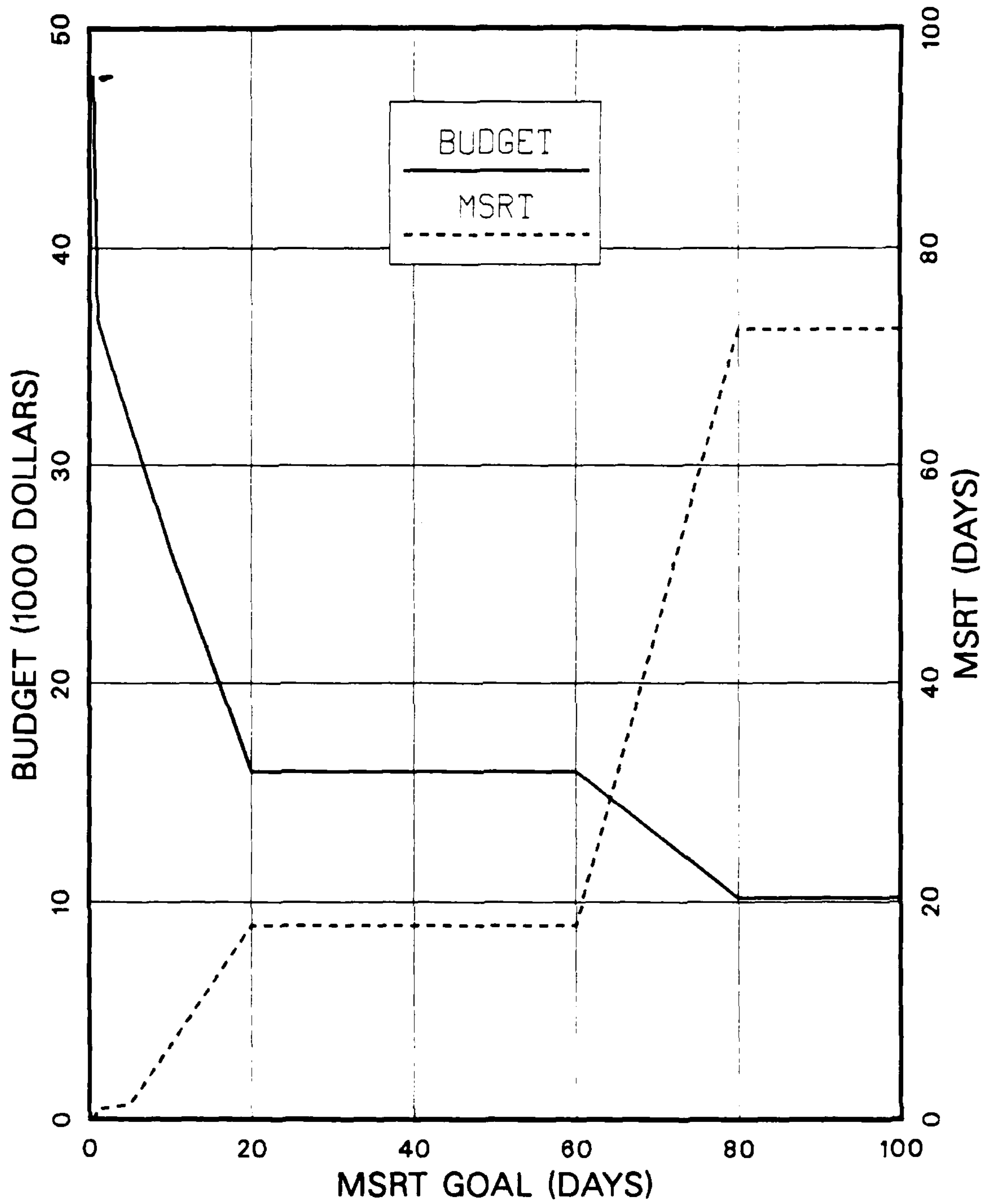


Figure G.17. VAV/1R; Marginal analysis budget and MSRT values for a range of MSRT goals.

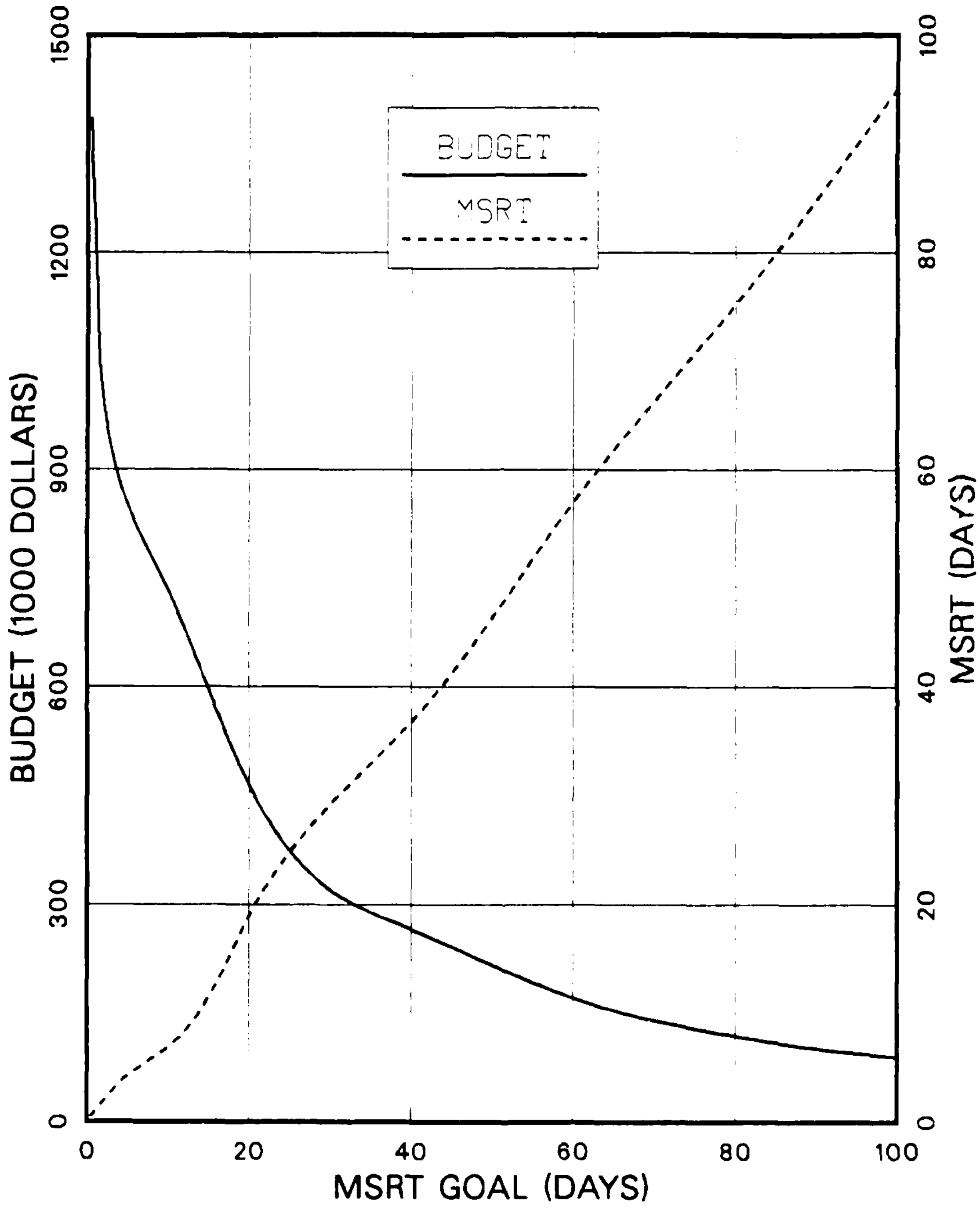


Figure G.18. VAV/2R; Marginal analysis budget and MSRT values for a range of MSRT goals.

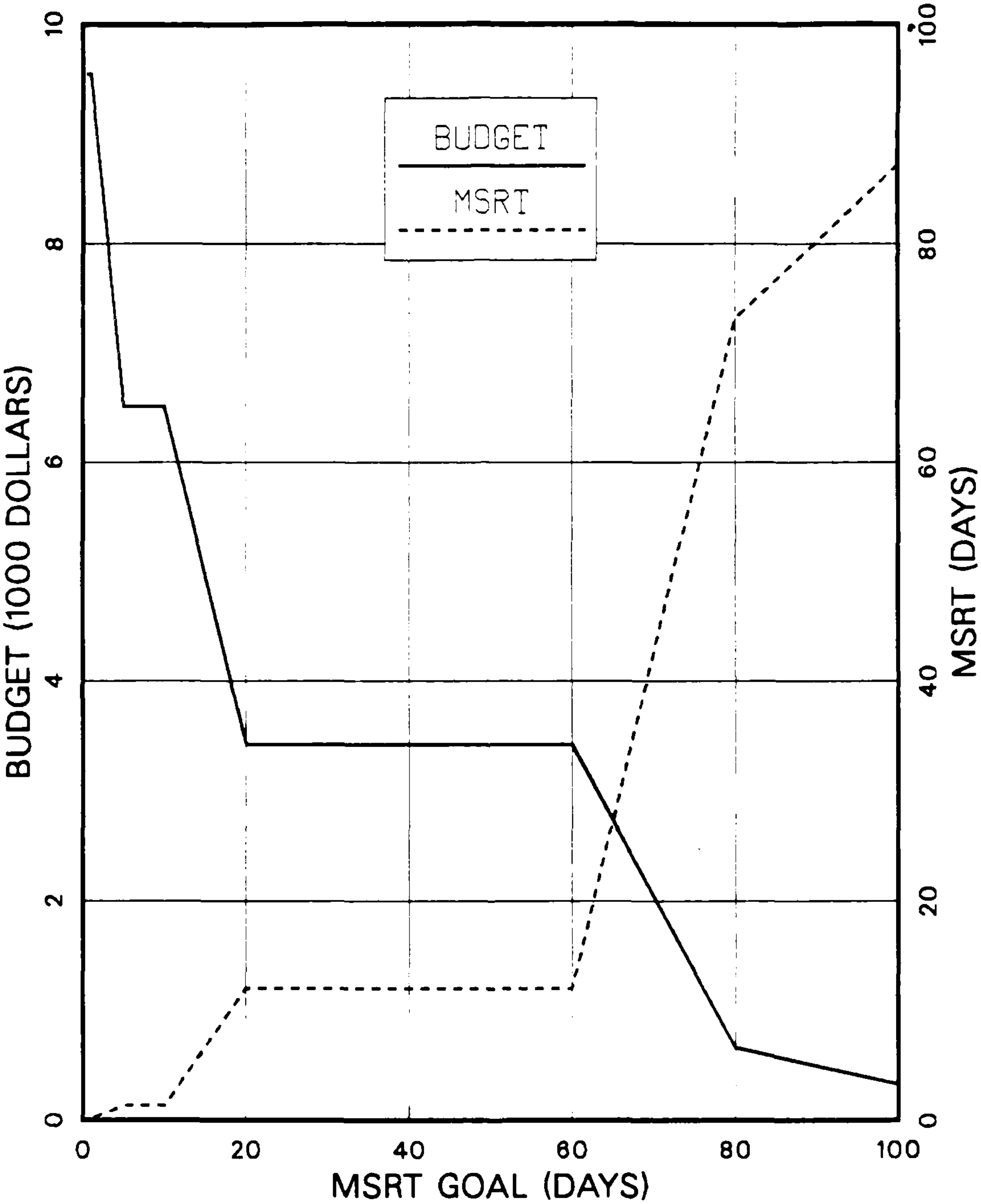


Figure G.19. V2J/1R; Marginal analysis budget and MSRT values for a range of MSRT goals.

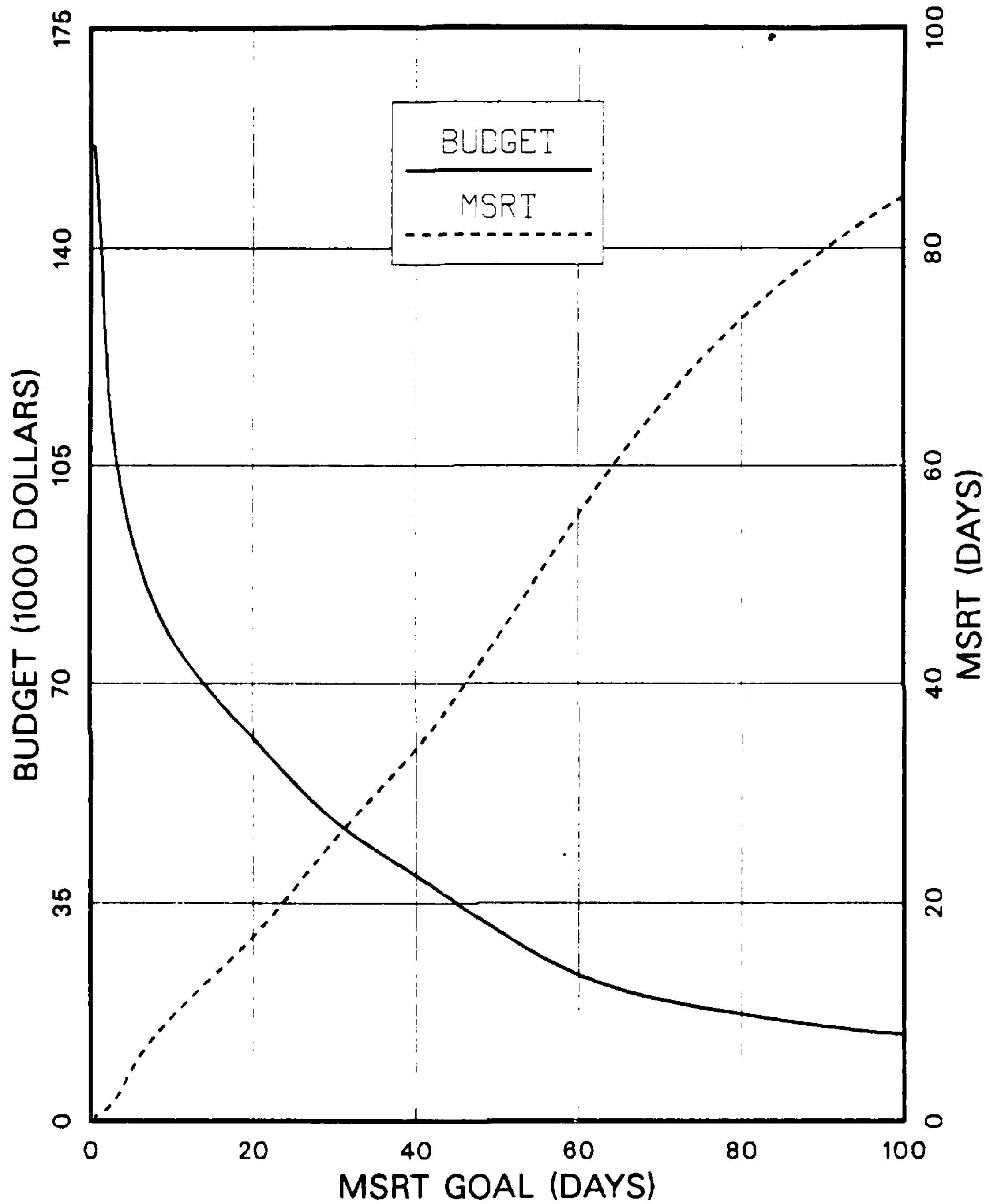


Figure G.20. V2J/2R; Marginal analysis budget and MSRT values for a range of MSRT goals.

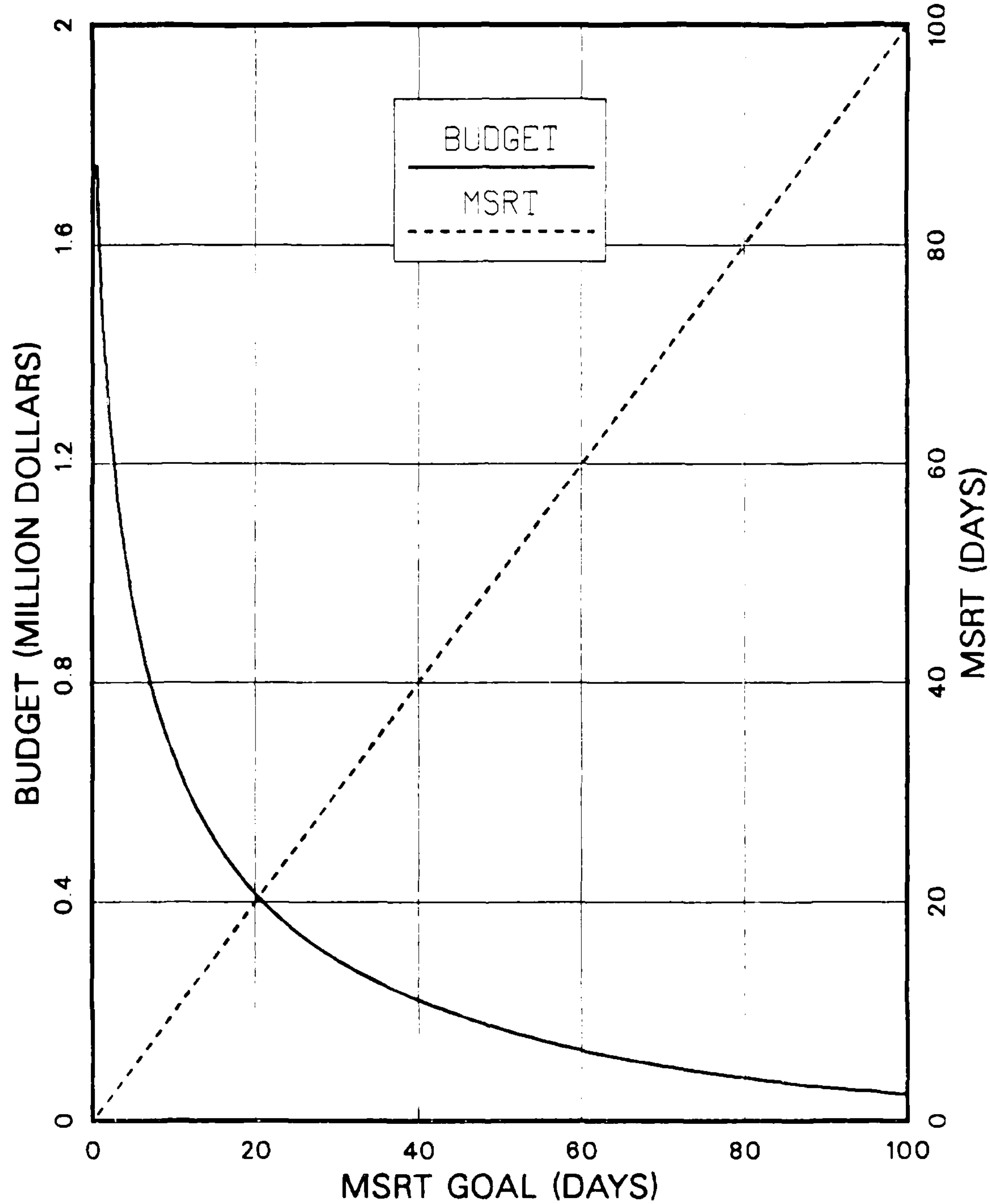


Figure G.21. ABR/1R; Marginal analysis budget and MSRT values for a range of MSRT goals.

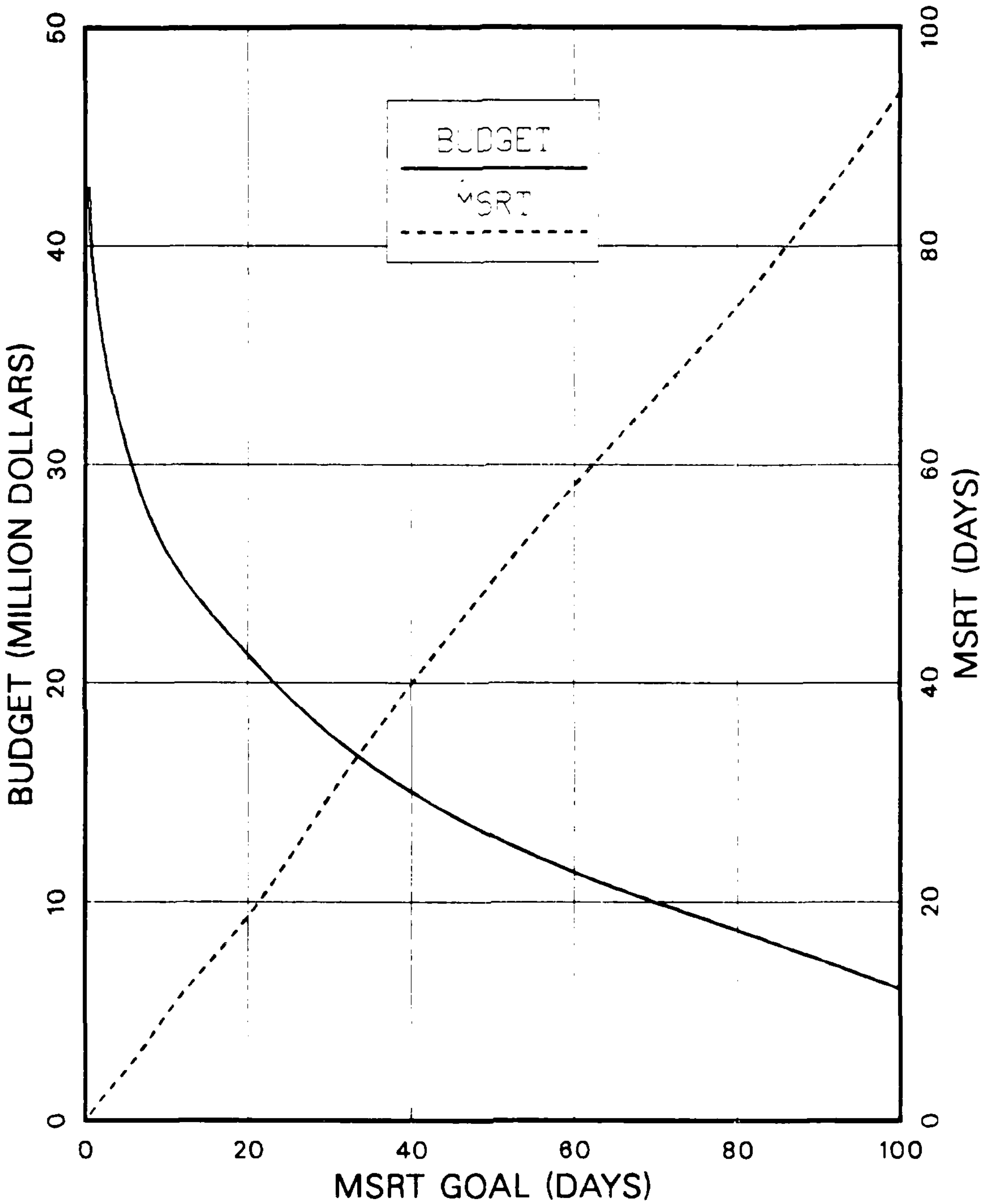


Figure G.22. ABR/2R; Marginal analysis budget and MSRT values for a range of MSRT goals.

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